EVALUATION OF SPAWNING HABITAT REQUIREMENTS FOR A SYMPATRIC PAIR OF LARGE AND SMALL BODIED LAKE UTOPIA RAINBOW SMELT

D. MacDonald

Population Ecology Division
Fisheries and Oceans Canada
531 Brandy Cove Road
Saint Andrews, NB
E5B 2L9

2017

Canadian Technical Report of Fisheries and Aquatic Sciences 3193

Fisheries and Oceans Canada | Pêches et Océans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts.*

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques.*

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Canadian Technical Report of
Fisheries and Aquatic Sciences 3193

2017

Evaluation of Spawning Habitat Requirements for a Sympatric Pair of Large and Small Bodied Populations of Lake Utopia Rainbow Smelt

by

D. MacDonald

Population Ecology Division
Fisheries and Oceans Canada
531 Brandy Cove Road
Saint Andrews, NB
E5B 2L9
Email: Danielle.MacDonald@dfo-mpo.gc.ca

© Her Majesty the Queen in Right of Canada, 2017.
Cat. No. Fs97-6/3193E-PDF ISBN 978-0-660-07143-5 ISSN 1488-5379

Correct citation for this publication:

MacDonald, D. 2017. Evaluation of Spawning Habitat Requirements for a sympatric pair of large and small bodied populations of Lake Utopia Rainbow Smelt. Can. Tech. Rep. Fish. Aquat. Sci. 3193: v + 47.

TABLE OF CONTENTS

Abstract and Résumé iv

Introduction 1

Study Site 3

Methods 5

- Temperature 5
- 2002 LURS Spawning Activity and Habitat Mapping 5
- 2015 LbP Spawning Activity and Habitat/Threat Identification 5
- 2015 SbP Spawning Activity and Habitat Mapping 6
- Habitat comparisons of selected vs. unselected Lake Utopia streams 6
- Statistical Analyses 7

Results 7

- Temperature 7
  - LURS LbP Spawning 7
  - LURS SbP Spawning 8
- LbP Spawning and Use of Habitat 9
- SbP Spawning and Use of Habitat 10
- Comparing LURS SbP spawning stream habitat with other Lake Utopia Streams 12

Discussion 13

- Temperature 13
  - LURS LbP Spawning 13
  - LURS SbP Spawning 14
- Habitat Features and Attributes 15
- Selected vs. Unselected Spawning Streams for SbP smelt 18

Conclusions and Recommendations 19

Acknowledgements 20

References 20

Tables 23

Figures 31

Appendix 44

ABSTRACT

MacDonald, D. 2017. Evaluation of Spawning Habitat Requirements for a sympatric pair of large and small bodied populations of Lake Utopia Rainbow Smelt. Can. Tech. Rep. Fish. Aquat. Sci. 3193: v + 47.

While Rainbow Smelt are known to be spawning habitat generalists, certain characteristics of Lake Utopia Rainbow Smelt (LURS) spawning streams were found to be unique and play an important role in determining where LURS spawn. Temperature profiles of Large-bodied (LbP) smelt spawning streams were significantly warmer ($\bar{x}$=3.59°C ± 2.0°C) than Small-bodied (SbP) spawning streams and non-spawning streams during the large-bodied smelt spawning and incubation periods (late March through April) ($H(6)=29.2901$, $p < 0.0001$) and they continued to be warmer throughout the SbP spawning and incubation periods (12.01°C ± 3.56°C) (late April through May). Small-bodied smelt spawning streams were not significantly different from most other unselected streams around the lake during their spawning and incubation periods but were significantly cooler than the large-bodied streams (e.g. Smelt Brook 6.89°C ± 2.16°C). Other habitat attributes that showed significant difference between selected and unselected stream sections for SbP spawning were: 1) habitat feature-type, with riffles and runs containing the most egg deposition; 2) presence of partial barriers, most eggs were found just below a barrier or between an upstream and a downstream barrier; 3) substrate type, most eggs were found on sand and gravel. The only unselected stream that was similar to SbP spawning streams in temperature and habitat features and attributes was Big Hike Brook and this should be monitored for possible spawning activity in the future. LbP smelt spawning was not evident in Mill Lake Stream in 2014 or 2015, likely the result of a culvert at the downstream portion of the stream impeding upstream passage due to water flows exceeding the maximum swimming speed of smelt. Confirmation of the presence of SbP smelt in Mill Lake Stream and their likelihood of spawning in this stream should encourage further monitoring of Mill Lake Stream as important spawning habitat for both populations of LURS.

RÉSUMÉ

Bien que l'éperlan arc-en-ciel soit connu pour être une espèce généraliste en matière d'habitat de frai, certaines caractéristiques des cours d'eau de frai de l'éperlan arc-en-ciel du lac Utopia se sont révélées uniques et jouent un rôle important dans la détermination de l'emplacement de frai de ce poisson. Les profils de la température des cours d'eau de frai de l'éperlan de grande taille (grand éperlan) étaient considérablement plus chauds ($\bar{x}$ = 3,59°C ± 2,0°C) que les cours d'eau de frai de l'éperlan de petite taille (petit éperlan) et les cours d'eau non destinés à la reproduction lors des périodes de frai et d'incubation de l'éperlan de grande taille (de la fin mars à avril) ($H(6)$ = 29,2901, $p < 0,0001$). Les profils de la température ont continué d'être plus chauds tout au long des périodes de frai et d'incubation du petit éperlan (12,01°C ±

3,56°C) (de la fin d'avril jusqu'à mai). Les cours d'eau de frai du petit éperlan n'étaient pas très différents de la plupart des autres cours d'eau non choisis autour du lac pendant ses périodes de frai et d'incubation, mais étaient beaucoup plus froids que les cours d'eau de frai du grand éperlan (p. ex., ruisseau Smelt 6,89°C ± 2,16°C). Les autres attributs de l'habitat présentant d'importantes différences entre les tronçons de cours d'eau choisis et non choisis pour le frai du petit éperlan étaient : 1) le type de composantes de l'habitat, avec des rapides et des ruisselets contenant des œufs; 2) la présence d'obstacles partiels; la plupart des œufs ont été retrouvés juste en dessous d'un obstacle ou entre un obstacle situé en amont et un obstacle situé en aval; 3) le type de substrat; la plupart des œufs ont été retrouvés sur du sable et du gravier. Le seul cours d'eau non choisi qui était semblable au cours d'eau de frai du petit éperlan en ce qui concerne la température et les composantes et les attributs de l'habitat était le ruisseau Big Hike. Ce dernier devrait être surveillé pour déceler d'éventuelles activités de frai à l'avenir. Il n'y avait pas d'éléments probants concernant le frai du petit éperlan arc-en-ciel du lac Utopia dans la décharge du lac Mill en 2014 ou en 2015. Cela était probablement attribuable au ponceau situé sur la partie aval du cours d'eau qui entravait le passage en amont en raison des débits d'eau dépassant la vitesse de nage maximale de l'éperlan. La confirmation de la présence du petit éperlan dans la décharge du lac Mill et sa probabilité de frayer dans ce cours d'eau devraient favoriser une surveillance accrue de la décharge du lac Mill à titre d'habitat de frai important pour les deux populations d'éperlan arc-en-ciel du lac Utopia.

INTRODUCTION

The Rainbow Smelt, *Osmerus mordax*, is a diverse species that can be found throughout eastern North America, from Labrador to New Jersey and as far inland as the Great Lakes (Scott and Crossman 1973). It has a dynamic taxonomic history complicated by its varying life history traits and strategies; anadromous, freshwater and landlocked populations exist, as well as co-occurring large and small body types (Nellbring 1989). At one time, morphological differences in body sizes were used as evidence of separate species (Rupp 1959) but are now generally considered sympatric pairs of *O. mordax*.

Co-occurring morpho-types and sympatric populations of Rainbow Smelt have been documented in various lakes including: Lake Champlain, Vermont (Greene 1930), Lake Héney, Quebec (Legault and Delisle 1968), Black River Pond, Newfoundland (Bruce 1975), Lochaber Lake, Nova Scotia (Taylor and Bentzen, Rivard 2016), and Lake Utopia, New Brunswick (Taylor and Bentzen 1993, Curry 2004, Bradbury et al. 2011). In the Gulf of St. Lawrence, Lecomte and Dodson (2005) documented reproductively discrete north- and south-shore populations of anadromous smelt. Sympatric populations of smelt, while differing in body sizes, also differ in ecological, morphological and genetic traits. Lanteigne and McAllister (1983) determined that gill raker counts were the most accurate distinguishing meristic characteristic; small-bodied populations have higher gill raker counts than the large-bodied forms. Sympatric populations are also reproductively isolated from one another temporally and/or spatially. This reproductive isolation serves to maintain distinct genotypic and phenotypic characteristics for each population (Taylor and Bentzen 1993, Lanteigne and McAllister 1983).

Lake Utopia Rainbow Smelt (LURS) consist of a sympatric pair of large and small-bodied populations (LbP and SbP respectively). A study by MacLeod (1922), states that there would seem to be two kinds of smelt in Lake Utopia, one kind being much larger than the other. Smelt have been an important feature of this lake and were discussed in the literature by naturalists as early as the 1800s (Osgood 1875) and as part of scientific literature since the early 1900s.

In 2000, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) recommended a threatened status for the then named "Lake Utopia Dwarf Smelt" (LUDS) (COSEWIC 2000). The LUDS was listed as Threatened on Schedule 1 of the *Species at Risk Act* (SARA) when the Act came into force in 2003. In 2008, COSEWIC recognized that both large-bodied and small-bodied populations existed in Lake Utopia and designated each as Threatened (COSEWIC 2008). Designation reasons included: their identification as being a genetically divergent sympatric pair of *Osmerus*; they are endemic to a single lake in Canada with an extremely small index of area of occupancy

(6 sq. km); SbP spawn in only three small, ephemeral streams in the watershed; and they could quickly become extinct through degradation of spawning streams and lake habitat, impacts of fishing, and the introduction of exotic species. The SbP remains on Schedule 1 of the SARA and a listing decision is pending for the large-bodied population (as of May 2016).

The Canadian *Species at Risk Act* defines critical habitat as the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the Recovery Strategy or in an Action Plan for the species (SARA s. 2(1)). Simply put, it is the habitat required for the species to be able to survive and to recover and may include nursery, breeding, or feeding areas. The Recovery Strategy for the SbP identifies sections of three streams entering Lake Utopia as Critical Habitat (Smelt Brook, Unnamed Brook, and Second Brook) for both spawning adults and developing eggs (DFO 2016a). These streams are thought to be more suitable for spawning smelt than other streams because of habitat characteristics that include: stream substrate, water flow, water temperature, depth, and access. Of 17 available Lake Utopia tributaries, these are the only three streams where LURS-SbP spawning has been consistently observed and in high abundance (Taylor and Bentzen 1993, Curry et al. 2004). The reasons why only these streams are utilized remains unclear.

Rainbow Smelt are known to spawn in a variety of habitats with varying substrate types (Rupp 1959). Most smelt spawning (including anadromous smelt) occurs in streams and rivers that drain into coastal or lake waters (Scott and Crossman 1973). Generally, spawning may begin as early as ice-out in late March and continue through May. Spawning times vary among populations and may depend on locality and temperature (McKenzie 1964). Smelt typically ascend streams late at night and lay their eggs in darkness (Creaser 1925, Rupp 1959, McKenzie 1964, Curry et al. 2004, Shaw and Curry 2011). Spawning occurs *en* masse with males and females congregated in small areas where eggs and milt are broadcast over the substrate (Creaser 1925, Langlois 1935, Rupp 1959). Smelt do not create nests for their eggs. Smelt lay demersal, adhesive eggs (Rothschild 1961, Scott and Crossman 1973), creating egg mats that are often several egg layers thick. The eggs incubate for approximately 3-4 weeks, depending on temperature (Curry et al. 2004, Shaw 2006), upon when the larvae hatch and drift downstream into either the lake or coastal waters.

The Lake Utopia Rainbow Smelt Recovery Strategy Schedule of Studies identifies activities to be undertaken to better understand the role of Critical Habitat attributes that provide for LURS life functions in both tributary and lake habitat so that a better understanding of their role in Critical Habitat can lead to more comprehensive protection of critical habitat (DFO 2016a). The objectives of this study were to: 1) confirm Mill Lake Stream as spawning habitat for LURS in 2015 (SbP and LbP populations); 2) confirm spawning activity and refinement of the upper and lower limits of spawning in the three

LURS SbP spawning streams (SbP population); 3) assess habitat characteristics and water temperatures of streams associated with LURS spawning; 4) compare spawning habitat attributes of confirmed LURS SbP streams to other Lake Utopia streams to determine their likelihood as suitable LURS SbP spawning habitat.

STUDY SITE

Lake Utopia (45.17°N, 66.79°W) is an oligotrophic to mesotrophic lake that drains into the Magaguadavic River in southwestern New Brunswick, Canada (Figure 1). The lake is approximately 13.8 km^2, and is roughly rectangular in shape with a maximum length and width of 7.1 km and 2.6 km respectively. There are two deep basins in the lake, referred to as the upper and lower basins (north and south locations), with maximum depths of 30 m and 20 m respectively. The average depth of the lake is 11.1 m. Two lake systems (Trout and Mill Lakes) drain into Lake Utopia as do other small streams scattered around the lake (Brylinsky 2009). The lake drains naturally via the Canal (2.6 km length) into the Magaguadavic River, however, water from the river will back up into the lake during periods of very high water and spring freshet (Brylinsky 2009, NATECH Environmental Services Inc. 2009). The Magaguadavic River drains into the Bay of Fundy via a large waterfall near its mouth (Carr et al. 2004). This area is also dammed by the St. George Power Company and water levels in the river and in Lake Utopia are influenced by their water management plan (St. George Power Limited Partnership 2012).

The Recovery Strategy (DFO 2016a) lists 5 tributaries as important spawning and nursery habitats for LURS. The LbP LURS have been observed spawning in two of these: Mill Lake Stream and Trout Lake Stream. The other three streams are along the northern shore of the Lake and contain varying amounts of SbP LURS spawning habitat: Second Brook, Unnamed Brook, and Smelt Brook.

Mill Lake Stream drains Mill Lake and its watershed into Lake Utopia (Figure 1). The stream is relatively short (~150 m) and contains varying habitat types including: riffles, runs, and a small waterfall. The waterfall is considered the upstream barrier to smelt migration (i.e. too high for smelt to jump) except during periods of flooding. Several meters (~116 m) of suitable smelt spawning habitat present between the falls and the old dam at Mill Lake are only accessible when the lake level is so high that the water backs up from Lake Utopia into Mill Lake Stream and floods the falls. There are less than 50 meters of suitable spawning habitat between the falls and the beaver pond area in Mill Lake Stream resulting in very restricted spawning habitat availability for LURS LbP.

The stream has been heavily impacted by beaver activity in some years, e.g., 2014 and 2016 (DFO unpublished data). This resulted in a large section of the stream (~60 m) now functioning more like beaver pond habitat.

Mill Lake Stream drains beneath Route 785 via two culverts: the primary and largest culvert is the main outflow and the other (at a higher elevation) is an overflow culvert which becomes operational during high water periods such as the spring freshet. The primary culvert may act as an upstream barrier to smelt migration during high water flows that results in water velocities stronger than smelt are known to swim (>40 cm/s, Peake 2008). In 2014, DFO staff noticed that during low water conditions, the main culvert was partially blocked by large boulders that were suspected to have fallen from the stream bank creating a small cascade too high for the smelt to jump. The area of the stream below the culvert becomes part of the lake habitat in the spring due to flooding and the stream characteristics temporarily shift to lake characteristics.

Trout Lake Stream drains Trout Lake and its watershed directly into Lake Utopia (Figure 1). It is mainly composed of run type habitat that passes through marsh and meadow areas before draining through a large culvert into Lake Utopia. This culvert is not considered a barrier to smelt passage although water flows at peak flow have not been measured to confirm their suitability for smelt.

Spear Brook is a tributary of Trout Lake (Figure 1) and has been shown to support LURS LbP spawning in some years (Curry et al. 2004). The stream is much wider and deeper than Mill Lake Stream. The upstream portion meanders through forested areas but much of the lower portion drains through marsh and meadows. While the mouth of Spear Brook is typically braided, DFO personnel noted in 2013 that beaver activity at the mouth of Spear Brook (Trout Lake end) had further divided the main channel of the stream into several smaller channels. Many of the channels appeared to end blindly and created a maze of channels through the marsh.

The three LURS SbP (Second, Unnamed and Smelt) streams at the northern end of the lake are all small first order streams that meander downstream through mainly forest habitat until just before their openings into Lake Utopia (Figure 1). During the 2015 spawning season, the LURS SbP streams averaged only 1-2 m wide with depths ranging from a few centimeters to 2 m. The lower parts of each of the streams are surrounded by meadow type habitat and the streams cut through channels in the sandy beach that open directly into the lake. Second Brook has the most accessible habitat of these streams and Unnamed Brook the least, ~330 m and ~100 m respectively (DFO 2016a). Upstream barriers on Second and Smelt Brooks are mainly formed of collected organic material (branches and leaves) and as a result the upstream limits may vary from year to year. The upstream barrier in Unnamed Brook is more stable, composed of small cascades throughout a boulder field with increased gradient (DFO 2016a).

METHODS

TEMPERATURE

In 2002, the New Brunswick Department of Natural Resources (NBDNR) conducted a LURS presence/absence survey from April 16 to May 13. During each site visit, temperature (0.1°C) was recorded by personnel using a handheld thermometer along the stream bank. Temperatures were recorded at various times of the day and timing was inconsistent among streams.

Temperature loggers (HOBO®) were deployed by DFO-Science on May 1, 2013 in Mill Lake Stream, Spear Brook (Trout Lake tributary), Smelt Brook, Unnamed Brook, Second Brook, Otter Brook, an unnamed stream (referred to as Big Hike Brook in this report) on the mid-west side of the lake (45.17°N, 66.80°W) north of the Canal, and an unnamed stream (referred to as Leavitt's Cove Brook in this report) (45.16°N, -66.77W°) that drains along the southern edge of Leavitt's Cove in late April 2013 (Figure 1). All data loggers were placed in the upper most accessible habitat. Loggers were set to record the average water temperature once per hour to the nearest 0.001°C. Loggers were collected and downloaded on various dates in 2014 and some redeployed and data collected again in 2015. The Spear Brook data logger could not be found in 2015 so data from April 5, 2014 through 2015 were not available for this report. In addition to temperature data, dates when smelt were present in the streams were also noted.

2002 LURS SPAWNING ACTIVITY AND HABITAT MAPPING

In 2002, under contract with the Department of Fisheries and Oceans, NBDNR conducted a comprehensive tributary survey to look for evidence of spawning by LURS SbP and LbP in as many as 18 Lake Utopia tributaries. The objective of the study was to identify streams with LURS spawning and this information was used to help identify critical stream habitat in the LURS SbP recovery strategy. Tributaries were monitored between April 16 and May 13 and streams with no evidence of spawning were not revisited. Observers made notes regarding the presence of eggs and smelt for each stream (as a single unit) and some qualitative notes were recorded regarding the observed habitat and the streams' potential as spawning habitat. Some detailed habitat classification was done by NBDNR in early July 2002 for Second, Unnamed and Smelt Brooks. Data collected included substrate type and proportion data.

2015 LBP SPAWNING ACTIVITY AND HABITAT/THREAT IDENTIFICATION

Mill Lake Stream was monitored weekly for evidence of spawning from April 1 to May 5, 2015. Monitoring occurred during the daytime except for one night time observation on April 30. The criterion to determine spawning timing and to define spawning habitat was the presence of eggs in either the stream or along the lake shore adjacent to the stream mouth. Stream flows at the primary culvert outflow were taken with a Flow Probe

(Global Water) digital water velocity meter at each visit. Photographs of the water level at the primary culvert and the upstream waterfall were also taken at each visit. Lake level data was collected from Saint George Power website (http://www.stgeorgepower.ca/st-george-power-todays-operation.aspx) and used to correspond with photographed levels at the culvert and falls. These data were used to determine the likelihood of fish passage through these structures.

2015 SBP SPAWNING ACTIVITY AND HABITAT MAPPING

Evidence of spawning by LURS SbP was monitored once in April (April 22) at Second Brook and then sporadically for all 3 SbP streams in May. Once eggs were observed, upper and lower limits for eggs and smelt were georeferenced. A few days later, a second visit to each stream was done to reconfirm the limits and to observe if any upstream migration and spawning had occurred after some full barriers were partially breached on the first visit. Where upper limits had moved upstream, new coordinates were recorded.

In 2015, Second Brook was chosen as the study stream for detailed habitat mapping because it was the longest, contained many spawning smelt and egg mats, and was the easiest to access. The objective of the detailed habitat mapping was to further refine habitat characteristics that may be important for spawning smelt and to compare substrate characteristics with the 2002 data. Mapping was based on modified guidelines and methodology from the Canadian Biomonitoring Network (CABIN) *Wadeable Streams* mapping and field sampling protocols (EC 2012). Moving upstream from the mouth, sections of the stream were delineated by habitat type (features qualified as riffle, run or pool) and a length measurement of each section taken. Data collected for each section included: % canopy cover, substrate types (size classifications differed from those in 2002) and proportions, presence of full or partial barriers, and presence/absence of eggs.

The stream was also mapped to capture stream shape and location of egg mats. Digital photographs were taken upstream and downstream at each section to capture unique habitat features and/or stream morphology (Figure 2). A GPS digital track of the stream was conducted to provide an accurate map that coincides with the habitat features and data collected along its length.

HABITAT COMPARISONS OF SELECTED VS. UNSELECTED LAKE UTOPIA STREAMS

Qualitative comparisons of habitat features shared by Second Brook and other Lake Utopia streams were conducted using digital photographs taken in varying years including: 2013, 2014, and 2015. Characteristics identified from the photographs were

compared with those of Second Brook so that their potential suitability as spawning habitat relative to known spawning locations could be determined.

Additional information was considered from the 2002 tributary survey that included observed stream conditions and a qualitative assessment of the stream's potential as suitable spawning habitat.

STATISTICAL ANALYSES

A graphical analysis of daily stream temperature variation was conducted for the April 23 to May 30, 2014 SbP spawning and incubation period to determine if spawning stream temperatures were more stable or variable than non-spawning streams over the spawning period and to determine if daily maximum or minimum temperatures were more suitable for describing temperature characteristics of streams than daily mean temperatures.

R statistical software (version 3.1.3) was used for statistical analyses (R Core Team (2013)). Temperatures were averaged to give a mean daily temperature for each date for each stream. Kruskal-Wallis non-parametric rank sum tests were used to compare daily average temperatures among the streams in 2014 since it is the most complete data set. Tests were conducted to look at temperature differences over the entire spawning and incubation periods for each population type and then the period was broken into a SbP pre-spawn/spawning period and a SbP incubation period (Table 1). When significant differences were detected by the Kruskal-Wallis test ($p<0.05$), a Kruskal-Wallis Multiple Comparison test was conducted to determine which streams were significantly different from one another.

Stream sections were categorized as selected or unselected for spawning based on the presence or absence of eggs. Substrate was divided into size classes based on the CABIN protocols. Proportions of each size class were estimated for selected and unselected sites and these were compared using Kruskal-Wallis non-parametric rank sum tests and a Kruskal-Wallis Multiple Comparison test. Habitat attributes of canopy, habitat type (e.g. run, riffle, pool), and barrier presence for selected and unselected sites were compared using Kruskal-Wallis rank sum tests and multiple comparisons tests for Second Brook data.

RESULTS

TEMPERATURE

LURS LbP Spawning

Temperature data from 2002 (measured only once per stream date check) indicated that Mill Lake Stream was warmer than Spear Brook by at least 2°C during the April

survey dates and that Spear Brook temperatures were more similar to SbP streams. Mill Lake Stream also remained warmer than the other LURS SbP streams throughout the April 16 to May 6, 2002 survey period (no further temperature data for Mill Lake Stream was captured beyond that date) (Appendix 1).

Mill Lake Stream was warmer than all other streams throughout the 2014 spawning period. This stream also warmed more quickly than all other surveyed tributaries. Mature fish were first observed on April 1 that year (Table 8) and this coincided with a period of declining daily average water temperatures beginning on March 30 and continuing through the spring freshet. Daily means did not reach pre-freshet temperatures until around April 12 when temperatures began an increasing trend (Figure 3). Mill Lake Stream was significantly warmer ($\bar{x}$=3.59°C ± 2.0°C) than all other sampled streams during the March 23-April 30, 2014 period of pre-spawn through hatch ($H(6)$=29.2901, $p < 0.0001$) (Table 1 and 2; Figure 3). Spear Brook data was only available for the period of March 15-April 4, 2014 and a Kruskal-Wallis multiple comparison test showed there was no significant difference between Mill Lake Stream and Spear Brook for that period while the SbP stream temperatures remained significantly different from Mill Lake Stream (p=0.05, critical difference = 54.31841). Temperature comparison of Mill Lake Stream in 2014 and 2015 and with Spear Brook for the March 15 to April 4, 2014 period showed significant differences ($H(2)$=17.8421, $p < 0.001$). Mill Lake Stream was significantly warmer during the 2014 time period ($\bar{x}$=2.37°C ± 0.81°C) than in 2015 ($\bar{x}$=1.30°C ± 0.26°C). In 2014, Mill Lake Stream was also warmer than Spear Brook (($\bar{x}$=1.47°C ± 0.68°C).

LURS SbP Spawning

Test results revealed significant differences in mean temperatures among the SbP streams during the April 23, 2014 to May 30, 2014 spawning and incubation period ($H(6)$= 78.9103, , p = 5.998e-15). Comparisons of the mean ranks among streams indicated that Mill Lake Stream was significantly warmer than the three known SbP streams during this period (Table 1 and 3). None of the SbP stream mean temperatures were significantly different. Second Brook was the warmest of the 3 SbP streams followed by Smelt and Unnamed Brooks (Table 1). There were no significant differences in mean temperature among Big Hike Brook and the three SbP Streams during this period (Table 3). The three SbP spawning streams and Big Hike Brook remained the coolest of all the studied Lake Utopia Streams throughout the SbP spawning and incubation period through to mid-June, 2014. Since a graphical analysis (Figure 3) revealed diverging temperature trends during the SbP spawning and incubation period, it was divided into 2 parts: pre-spawn/spawning period from April 23-May 7 and a late spawning/ incubation period from May 8 to May 30 (based on an approximate 3 weeks incubation time). Results of the Kruskal-Wallis rank sum test for the pre-spawn/spawning period indicate that there is still a significant difference among the

streams ($H(6) = 53.7453$, $p < 0.0001$) and a multiple comparison test after Kruskal-Wallis showed no significant differences among the three SbP streams nor any of these with Big Hike Brook, Leavitt's Brook, or Otter Brook (Table 4). Of interest is that Second Brook, still the warmest of the three SbP brooks ($\bar{x}$=5.5°C ± 1.07°C), was not significantly different from Mill Lake Stream during this period. During the SbP incubation period, Mill Lake Stream was the warmest of all the streams ($\bar{x}$=14.57°C ± 1.38°C) and was significantly different from all others except for Otter Brook ($\bar{x}$=11.37°C ± 1.14°C) (Table 1 and 5). Second Brook remained the warmest of the three SbP streams and was significantly warmer than Unnamed Brook but was not significantly different from non-spawning streams: Leavitt's Cove Brook, Big Hike Brook and Otter Brook. Big Hike Brook temperatures continued to group with the three SbP streams (Table 5).

Box plots of daily temperature ranges revealed that there was an increased range in temperatures in early May 2014 (May 5-10) (Figure 4) and this period likely corresponded with increased spawning in the LURS SbP streams. This increased range in daily temperatures was also seen in the non-spawning streams and was more variable here than in the spawning streams (Figure 5c). Mill Lake Stream had warmer minimum and maximum daily temperatures than all other streams observed (Figure 5 top and middle graph) but had a narrower daily temperature range than non-spawning streams (Figure 5 bottom graph). The spawning streams continued to group together for daily minimum, maximum and ranges in temperature. Big Hike Brook, also grouped with the SbP streams while Otter Brook and Paper Mill Brook did not (Figure 5). There appears to be more daily temperature stability in the spawning streams than in the majority of non-spawning streams and spawning streams also exhibit less range in daily temperature values.

Temperatures recorded in 2002 (Appendix 1, Table 1) could not be evaluated statistically since they were collected on various dates and times and were inconsistently monitored among streams. Data does show that Mill Lake Stream was warmer than all other streams on April 22 at 7.5°C while Unnamed and Smelt Brooks were between 3.5°C and 4°C. Spear Brook was more intermediate at about 5.5°C. Mature LURS and eggs were observed at lower temperatures in 2002 (<5°C) than in 2014 (>5°C). Non-spawning streams (2002) were usually warmer than spawning streams when observed on the same dates (Appendix 1, Table1).

LBP SPAWNING AND USE OF HABITAT

Eggs and fairly thick egg mats were observed in Mill Lake Stream downstream of the waterfalls in 2002 on April 16. Eyed eggs were observed on April 22, 2002 and larvae were swimming in the eggs on May 6. Utilizing McKenzie's (1964) incubation time of 29 days at temperatures of 6°C-7°C, spawning likely began around the beginning of the second week of April that year. Eggs were also observed in Spear Brook just

downstream of a beaver dam as early as April 16, 2002 and similar eyed eggs with swimming larvae reported on May 7 (Appendix 1). This suggests that spawning of LbP in Spear Brook happened on similar dates as in Mill Lake Stream in 2002.

No smelt were observed in Mill Lake Stream in 2015. Day time observations began on April 1st when the lake was still covered with ice and continued through April to the ice-out date of April 28th. On April 29th a few smelt eggs were observed near the secondary culvert and at the base of the falls on Mill Lake Stream. The eggs could not be confirmed as LbP and were more likely to be of SbP origin based on corresponding spawning in the SbP streams. On April 30, 2015, the outlet area of Mill Lake Stream below the culvert was checked for eggs by boat and underwater camera and fewer than five were observed. No smelt or eggs were observed in Trout Lake Stream (culvert area) or Spear Brook in 2015.

Fish passage at the primary culvert in Mill Lake Stream was visually assessed as a potential problem in 2014 and 2015. No smelt were observed above the culvert in 2014 even though hundreds were observed in the area below the culvert. In 2015, water velocities were recorded at the culvert outflow to determine if the culvert was passable to smelt. On all dates checked, the flow at the culvert exceeded the threshold of 40 cm/s reported as passable by Peake (2008) (Table 6). As the lake level rose and filled the culvert, water flows decreased.

SBP SPAWNING AND USE OF HABITAT

Data from the 2002 spawning period indicates that spawning in the SbP streams occurred earlier than in recent years with eggs and/or smelt present in Unnamed Brook and Smelt Brook as early as April 22. Eggs and smelt were present in Second Brook on April 24, 2002. NBDNR personnel often noted that the habitat appeared to be unsuitable in non-spawning streams surveyed around Lake Utopia during the SbP spawning and incubation period. Many of these streams were described as having low water level, accessibility issues, and silt as a major substrate type (Appendix 1, Table1).

Eggs and smelt were observed in all three SbP streams in early May 2015. Several large egg mats were present in the streams indicating that spawning had started at least a few days previously, likely around the end of April. The geographic upper limits of egg deposition for each of the three SbP streams are reported in Table 7. There was a slight downstream shift in habitat use for both Smelt and Unnamed Brooks and a slight upstream expansion in Second Brook. In all streams, organic debris created full and partial barriers to upstream fish passage. Smelt were not able to get around or through many upstream barriers nor were they observed jumping over them. In Second Brook, one of the observed barriers was created by a partial blockage of the stream that resulted in water funnelling quickly through a small opening (Figure 6). Water velocity in the opening was ~1.42 m/s and the flow immediately above the pooling smelt just

downstream of the opening was 0.44 m/s. Some of the organic debris was removed by DFO personnel and resulted in decreased stream flow (below 0.5 m/s) (Figure 6). After a few minutes, smelt were observed swimming above this location and into upstream habitat.

Three major habitat types, riffles, runs, and pools, were present in Scout Brook and are presented as a proportion of the total habitat. Runs were the most common habitat type and represented 61% of the total mapped habitat; riffles and pools were equally present in the stream at 19.5% each. Habitat type was compared with selected (eggs present) and unselected sections of the stream. As a proportion of the entire stream utilized, eggs were mostly present in runs (61%) followed by riffles (23.8%) and pool habitat (14.3%). Riffle habitat was the most selected with 71% of available riffle habitat containing eggs. Run habitat, although the most present in the stream, was the second most selected with approximately 60% of this habitat containing eggs. Pools were the least selected of habitat types with only 43% of all pool habitat containing eggs.

Canopy coverage was observed as a percent of total coverage. There was no difference in canopy coverage for selected and unselected sites ($p = 0.5419$) with canopy coverage ranging from 0% to 90% in unselected sites ($\bar{x}$=42%) and 0% to 70% in selected sites ($\bar{x}$=42%).

The most prevalent substrate types in the stream were coarse sand (39.5%), fine sand (21.4%), organic cover (22.2%), and gravel (13.2%). The remaining substrates (<4%) were larger than 1.6 cm in diameter. Some boulders were present in the upper reaches of the streams. Smelt showed a preference for smaller substrate sizes with selected sites primarily composed of coarse sands, fine sands, organic matter and some gravel (Figure 7). There was a lot of variability in particle sizes (<0.1 cm to >25.6 cm) throughout sampled sections of the stream and proportions of substrate particle sizes significantly differed throughout the stream ($H(19)= 235.6119$, $p < 0.0001$). However, comparisons of the mean ranks between selected and unselected sites for each particle size category indicate that substrate particle sizes of the same category (e.g. organic cover, fine sand, coarse sand) did not differ significantly for selected and unselected sites (observed difference<critical difference of 128.38) nor did they significantly differ for selected sites among the size categories below 1.6 cm (observed difference<critical difference of 117.1941) (S0 to S3 in Figure 7).

Most egg mats were often found in areas just above a partial downstream barrier, just below a partial upstream barrier or between both types of barriers. Only 19% of selected sites had no partial barriers associated with the egg mats while 80% were associated with a barrier type. Of these, over 60% of selected sites had both partial upstream and downstream barriers.

The July 2002 habitat survey by NBDNR used different substrate and particle size categories than the 2015 survey. The most prevalent substrate types in 2002 were

gravel, sand and fines in all three LURS SbP spawning streams (Table 8). Most fines were found in the lowest reaches of the streams where the stream passed through wetland habitat before it drained across the beach and into the lake. Although there is overlap in particle sizes among categories between 2002 and 2015, the majority of the substrate in 2002, like in 2015, is smaller and composed of particles less than 53 mm.

COMPARING LURS SBP SPAWNING STREAM HABITAT WITH OTHER LAKE UTOPIA STREAMS

Photographic examination of non-LURS spawning streams was possible for the following: Otter Brook, Leavitt's Cove Brook, Big Hike Brook, Unnamed Brook #1 (45.152498°N, 66.785637°W), and Unnamed Brook #2 (45.150164°N, 66.816166°W) (Figure 1). None of these streams have previous reports of spawning smelt. Key visual features shared by LURS SbP spawning streams include drainage of the streams through a sand delta directly into the lake, substrate composition primarily of particle sizes < 1.6 cm, main spawning parts of streams flowing through a forested area, narrow streams (< 1 m on average) and shallow (≥0.30 m) in spawning areas with most egg deposition in runs, riffles and pool-tailings.

Otter Brook drains into the Canal via approximately 210 meters of wetland habitat. The habitat upstream is mostly in forested area. Parts of the stream were photographed in May 2015 (Figure 8). The stream is wider than known SbP streams (~2 to 4 m in wooded area with sections >50 m where it widens in wetland habitat near its mouth). Substrate in the forested area of the stream is much larger than that of the SbP streams and is primarily composed of pebble and cobble (3.2 to 25.6 cm) with many boulders scattered throughout the stream (Figure 8b and 8c). There is little organic cover. Habitat type in this area is primarily run-type with some riffles interspersed throughout. Depth in the forested portion is shallower (<0.5 m) than the wetland area (>0.5 m). The water is clear in colour. Observations in 2002 noted that there was no access restriction to the stream and it was evaluated as having some potential for spawning on April 22. By May 8, 2002, fine sedimentation and silt were observed in the stream and it was assessed at that time as having a low potential for spawning (Appendix 1, Table 1).

Leavitt's Cove Stream was examined in 2002, 2013, and 2014 (Figure 9). This stream is found on the east side of the lake and drains directly into the lake through more than 100 m of wetland habitat (Figure 9a). The area upstream of the drainage is mainly forested with large deciduous trees and canopy coverage less than 30% during spawning. The stream has a steeper gradient than LURS SbP streams and it meanders through many boulders (primary substrate type) resulting in many small cascades (Figure 9b). The average stream width is approximately 1.5 m to 2 m. A great deal of debris was found in the stream and the surrounding area. Most of this stream would be inaccessible to smelt as the boulder field creates many inaccessible barriers to

upstream movement. This stream does not contain habitat suitable for LURS SbP spawning.

Big Hike Brook drains directly into the mid-west portion of Lake Utopia through approximately 200 m of wetland habitat. The upstream portion meanders through a dense forest (Figure 10a and 10b) and canopy coverage was greater than 50% in this area in late April and early May. This stream is the most similar to the LURS SbP streams in its upper portions. It is very narrow (<1 m) and is primarily composed of run and riffle type habitat. Substrate is primarily <0.1 cm (fine silt and clay with some fine sand) (Figure 10c). There are many full and partial barriers composed of wood and leaf debris (Figure 10a). There does appear to be more sedimentation in this stream than in the three SbP streams. Depth in the forested portion of this stream is shallow (<20 cm) and was nearly dry in some areas in late April 2013 and was dry at about 150 m from the mouth in 2002 (Appendix 1, Table 1, Tributary 2). In years with adequate water flow, Big Hike Brook may contain habitat suitable for LURS SbP spawning.

Unnamed Brook #1 drains directly into the southeast area of Lake Utopia through a wetland area and then through a sandy beach delta. In 2013, the stream was found to be filled with woody debris and alder bushes (Figure 11a). The substrate was primarily mud and silt (<0.1cm). The brook was deemed inaccessible to smelt as a result of debris in the stream (Figure 11b). The stream was also assessed as no potential for spawning in 2002 (Appendix 1, Table 1: Tributary 12).

Unnamed Brook #2 is located on the southwest edge of the lake and drains directly into Lake Utopia via a wide channel through wetland habitat with adjacent beach areas. In 2013, this area was discovered to be impacted by a beaver dam near its mouth and was determined to be inaccessible to smelt (Figure 12). In 2002 it was assessed as unsuitable for spawning (Appendix 1, Table 1, Tributary 14).

DISCUSSION

Habitat attributes found to be associated with occupied spawning and incubation habitats for Lake Utopia Rainbow Smelt included stream temperatures, substrate sizes, habitat types, and the presence of partial barriers.

TEMPERATURE

LURS LbP Spawning

Temperature in Mill Lake Stream, a LURS LbP spawning stream, may be considered a habitat characteristic indicative of suitable spawning habitat. A review of previously reported LbP spawner observations in Mill Lake Stream (Table 9) shows spawners present as early as April 1 and as late as April 16 with temperatures when LbP spawners were present ranging from 1°C to 6°C and temperatures generally ranging

between 5°C and 6°C during the past 15 years. The arrival of mature fish in 2014 coincided with a decline in stream temperatures as the spring freshet took place. Mature fish presence at the Mill Lake Stream culvert in 2014 peaked between April 3 and April 10, the same period when water temperatures declined from the freshet. Not many smelt were observed after the pre-freshet daily mean temperature was reached again on April 12. Even though the freshet initially caused a decline in temperatures, Mill Lake Stream and Spear Brook were still warmer than all other Lake Utopia streams surveyed during the March 25 to April 4, 2014 time period. Previous studies by Curry et al. (2004) and Shaw (2006) also found that Mill Lake Stream was warmer than the three SbP streams in early April. This period is also associated with continued ice-cover in the lake, although the ice would be starting to thin and erode. In Lake Utopia, smelt are lake residents except in spring when they enter the streams and brooks to spawn (Curry et al. 2004, COSEWIC 2008, Bradford et al. 2012). Rupp (1959) felt it was more likely that temperature cues for spawning would come from the lake environment where the fish reside rather than from the spawning areas in the streams. Lake temperatures during the period of ice cover would be expected to be near 0°C near the surface and only slightly warmer at the bottom. Increasing water flows into Lake Utopia from Mill Lake Stream resulting from the spring freshet may result in a detectable warmer water plume entering the lake. Warmer stream water and detectable inflowing water currents into the lake may serve as attractants (Creaser 1925) to mature LbP smelt. Additionally, Mill Lake Stream is the drainage stream for Mill Lake which likely has warmer water throughout the winter/early spring seasons than surface and groundwater streams like those utilized by the SbP LURS.

LURS SbP Spawning

Temperature is a less likely predictor of suitable spawning habitat for LURS SbP spawning streams. Although mean daily temperatures were lower in SbP streams than LbP streams throughout the spawning and incubation periods, many non-spawning stream temperatures were similar to temperatures found in SbP streams, making temperature a less unique habitat characteristic. SbP stream temperatures reported in the literature for previous years (5°C-9°C) were consistent with those in 2015 (Table 10). As in previous studies, temperatures of SbP streams were not significantly different from one another during the SbP spawning period (late April through early May) (Curry et al. 2004, Shaw 2006). The thermal regime of the SbP streams became less unique as the season progressed and most non-spawning and spawning streams did not have significantly different mean temperatures over the incubation period. Second Brook warmed more quickly than the other 2 spawning streams and was significantly warmer than Unnamed Brook during the late spawn/incubation period. The timing of this temperature difference is likely less important as a cue for spawning than the similarities observed in the earlier spawning period when fish were actively moving upstream to

spawn. There was more variation in daily minimum and maximum temperatures in some of the non-spawning streams over the April 23 to May 30, 2014 period. Unlike the smaller SbP spawning streams, Otter Brook and Paper Mill Brook are wider and drain from wetland or lake habitat upstream. Otter Brook and Paper Mill Brook have less canopy coverage than the SbP spawning streams allowing for more warming and cooling from the sun's thermal energy. Big Hike Brook is another small first order stream and its temperature profile throughout the spawning and incubation periods was very similar to that of the three SbP streams. If temperature is a critical metric for suitability for spawning and incubation, Big Hike Brook should be further monitored for smelt spawning.

The use of Mill Lake Stream as SbP spawning habitat was raised in 2014 when the Maritimes Aboriginal Peoples Council (IKANAWTIKET 2014) reported smaller smelt present in this stream on April 22 (Table 10). A sample of these was sent for genetic testing and results indicated that 50% of fish sampled were of the pure small body morphotype while the others were from a group with increasing levels of hybridization with the large morophotype gene (P. Bentzen, pers.com.). These results provide evidence that mature SbP were in Mill Lake Stream in 2014. Visual observations of new eggs in the stream by DFO personnel on April 25th indicate that LURS SbP likely spawned in Mill Lake Stream in 2014. In 2015, new eggs were observed above the culvert in Mill Lake Stream on April 29th. A check of Second Brook on May 4th indicated that SbP spawning was well underway (several smelt and large egg mats in the stream). Since Second Brook and Mill Lake Stream are very close to one another, it is likely that the eggs spotted in Mill Lake Stream in 2015 were of SbP origin. Stream temperatures and smelt and/or egg presence in the SbP streams and Mill Lake Stream in 2014 and 2015 coincide with spawner presence in other years reported in the literature (Table 10).

Similar to temperature cues that initiate spawning for LURS LbP, temperature cues to initiate spawning by SbP smelt are likely experienced in the lake. Spawning in the SbP streams consistently occurs after ice-out in late April and early May. Rupp (1959) found that warming surface waters after ice-out began to create thermoclines in Maine Lakes and that these warming surface waters may be a cue for spawning. In addition, light penetration after ice-out is much greater and longer daylight is experienced, therefore, light cues may also be of importance for the start of spawning for SbP smelt.

HABITAT FEATURES AND ATTRIBUTES

Most freshwater fish have a preference for the habitat type they utilize for spawning. For example, Atlantic salmon (*Salmo salar*) spawn in gravel-bottom riffle areas above or below a pool where there is sufficient upwelling of water to aerate buried eggs (Scott and Crossman 1973, DFO 2014). Rainbow Smelt spawning has been described in a variety of habitats that include small streams, rivers, pools with adequate water flow,

and along lake shores (Hoover 1936, Rupp 1959, Rupp 1965, Curry et al. 2004, Bradford et al. 2012). In Second Brook, only three habitat types were present at the time of spawning: runs, riffles, and pools. While run-type habitat was the most prevalent in the stream and was highly utilized for smelt spawning, riffle habitat was preferred by smelt with over 70% of available riffle habitat containing eggs. Runs and riffles are areas of higher water flow and water flow may be the attribute preferred by smelt in these habitat types. Pools rarely contained eggs and are not preferred spawning habitat for LURS.

Previous studies have indicated that spawning smelt are substrate generalists and will spawn in areas with varying substrate types. Rupp (1959) indicated that smelt eggs in Maine lakes and tributaries were found on sand, boulders, aquatic vegetation, concrete, wood, and debris, but the preferred substrate appeared to be clean gravel or coarse sand. Langlois (1935) and Rothschild (1961) also found that smelt spawned in a mixture of coarse gravel and sand. In the three SbP streams of Lake Utopia, eggs were found attached to a variety of substrate types including boulders, aquatic vegetation, rocks, gravel and sand. In Second Brook, egg mats were primarily found in sections of the stream with high compositions of coarse sand. Some sections of the stream with this type of substrate did not have any egg deposition so while smelt may have a preference for coarse sand; it is not the only attribute that determines site selection. Since the majority of egg deposition was on substrate of gravel sized or smaller, it can be concluded that LURS SbP spawning streams require adequate amounts of substrate with particle sizes less than 1.6 cm.

Canopy coverage was considered as a potential habitat attribute since Creaser (1925) found that smelt had negative responses to light; they were able to stop an entire upstream run of smelt with lantern lights. Developing fish eggs and larvae are known to be light sensitive during their development and ultraviolet radiation can be damaging to developing embryos (Bell and Hoar 1950, Zagarese and Williamson 2001). The three SbP streams in Lake Utopia meander through forested habitat in their upland sections where most spawning occurs. Since spawning occurs in the spring before many leaves have emerged on deciduous trees, the forest canopy is more variable. The presence and absence of smelt eggs in canopied sections was found to be equal on Second Brook; average canopy coverage was 42% in both selected and unselected sections of the stream. Since smelt spawn at night, canopy coverage is not likely an important habitat attribute of spawning habitat.

Impassable barriers limit access to upstream habitat. Since LURS spawning habitat is already limited, any barriers that prevent access may have detrimental impacts on spawning year success and subsequent year-class abundance. A study by Peake (2008) determined that mean critical swimming speed for rainbow smelt was 38.2 cm/s (range: 30.1 to 45.6 cm/s) for smelt of mean length of 11.5 cm (range 7.0 to 16.0 cm) at

a mean water temperature of 10.0°C. This suggests that culverts containing water velocities less than the range of 30.0 to 40.0 cm/s will allow passage of most smelt sizes. Since the primary culvert water velocity exceeded 40 cm/s on all dates checked during the expected spawning season in 2015, and water temperatures were lower than 10.0°C, the culvert was a barrier to upstream smelt passage. The effects of this restriction to the areas of upstream spawning habitat are unknown. While thousands of mature smelt were observed at night at the downstream end of the culvert in 2014 (DFO 2016b), it is unknown where the majority of their spawning activities took place that year. Other lacustrine smelt populations are known to spawn along the shorelines (Rupp 1965, Scott and Crossman 1973) and in the deeper waters of lakes (Legault and Delisle 1968, Plosila 1984). Bradford et al. (2012) indicated that Lake Utopia surveys in 2009 and 2010, in the areas adjacent to known spawning tributaries, revealed no evidence of shoreline spawning for either population. While Mill Lake Stream is considered a LbP spawning tributary, its constricted habitat (<100 m of suitable habitat) and upstream passage issues during peak flows can render it overcrowded with eggs or inaccessible to spawners. McKenzie (1947) studied the effects of crowding on smelt eggs and determined that when egg density was 54,600/ft^2, only 46 larvae per 100,000 eggs survived to hatch, whereas 226 larvae were produced at a density of 23,300 eggs/ft^2.

A 2014 spawning population abundance study (DFO 2016b) found that the smelts captured below the Mill Lake Stream culvert in early April were of mixed sizes with many not meeting the greater than 17 cm length criteria for LbP smelts (DFO 2016a). Genetic analysis confirmed that the majority of these were large body morphotype, although some hybridization was also present (P. Bentzen pers. com.). The same study estimated the LURS LbP at approximately 22,741 spawners, however, egg deposition in Mill Lake Stream that year was sparse, likely due to high water flow through the primary culvert. It is unknown if spawning took place elsewhere that year nor if it will occur in other locations or at all when spawning habitat accessibility is limited. Taylor and Bentzen (1993) and DFO surveys in 2002 and 2003 found adult LbP smelt in Spear Brook and Trout Lake Stream. This stream, which is larger than Mill Lake Stream, has only been checked by daytime visual observation in recent years and detecting eggs and/or smelt in a large stream is very difficult. Since there is recent evidence of little egg deposition in Mill Lake Stream, a more comprehensive study in Trout Lake Stream may be warranted to determine its current status. Determining if LURS LbP smelts are spawning under the ice in deeper waters of either the lake or a larger stream could be difficult to determine.

Fallen organic matter has the potential to block the stream at any point along its length and these types of barriers are potential threats to spawning success in a given year. Barriers in the SbP streams were mainly composed of fallen trees, branches and leaves that clogged areas of the streams. These barriers were often small but created flow that

was too strong for smelt to swim through or the debris created a small cascade that was too high for the smelt to jump; in some instances the height difference was only a few centimetres. The location of these barriers change as new ones form and old ones deteriorate or get washed out. Limiting available spawning habitat could result in more egg deposition in contracted areas of the streams and would likely lead to lower egg survival. Partial barriers were prevalent throughout Second Brook in 2015. These partial barriers were highly associated with egg deposition with most eggs found between 2 barriers or immediately downstream of an upstream blockage. Hoover (1936) found that barriers preventing upstream movement seemed to induce spawning over the closest suitable area downstream. Smelt spawning on a given night is thought to begin when large numbers of smelt are congregating in the streams and the smelt are in close proximity of one another (Hoover 1936). Full and partial stream barriers function to cause aggregations of smelt in confined areas. These aggregations are likely important for the initiation and continuation of spawning. Many areas of the stream had no barriers and egg deposition was found to be much less in these sections. Partial barriers that constrict large numbers of smelt in small sections of the stream should be considered an important SbP spawning habitat attribute.

SELECTED VS. UNSELECTED SPAWNING STREAMS FOR SBP SMELT

While Lake Utopia has many tributaries, it is evident that the SbP smelt utilize only three streams along the northern lake shore. These streams have habitat attributes that include smaller substrate size, a lot of forested riparian zone, shallow depth, narrow wetted-width, drainage through a sand delta directly into the lake, and low gradients. While extensive habitat characterization was not done for the other lake tributaries, habitat characteristics that make these areas unsuitable were evident. Most of the unused streams were inaccessible to smelt as a result of barriers caused by beavers, debris or steep gradient. There was also a substrate mismatch between the selected and unselected streams with unselected streams having either higher proportions of substrate larger than 1.6 cm or a lot of fine sediment and siltation covering the bottom of the streams. Temperature profiles of unselected streams showed more variation throughout the spawning period and were often warmer than selected streams. Big Hike Brook was the only unselected stream that had many habitat features and attributes similar to the selected streams. While the upstream portions were similar to other SbP streams, there was little stream flow and the mouth of the stream passes through wetland rather than a beach delta. This stream has low discharge and was dried up within 150 m of the mouth in 2 years of observations (2002 and 2013). Low discharge rates likely make this stream unsuitable for smelt spawning despite many other similar habitat attributes.

Proximity of fish in the lake to spawning streams may be another selection criterion utilized by smelt. During the lake residency period, the smelt are thought to remain in

the cooler, deep water basins (Scott and Crossman 1973, DFO 2016a). Extending across from the inlet of Trout Lake to the west side of the lake and just east of Long Island to the inlet of Mill Lake is a large deep water basin with depths greater than 20 m and a maximum depth around 30 m (Figure 13)(NATECH Environmental Inc. 2009). Smelt residing in this area of the lake would receive cues from adjacent streams. All suitable and accessible tributaries in this northern portion of the lake are utilized for smelt spawning. A DFO survey conducted in 2013 of all Lake Utopia tributaries found that only 2 tributaries in the northern portion of the lake were unsuitable for smelt spawning: Little Otter Brook was blocked by an extensive and well established beaver dam, and another brook located at 45.19253° N , 066.805747° W was essentially a still water. Acoustic surveys to determine temporal and spatial use of the lake by Rainbow Smelt in Lake Utopia are recommended. This data could substantiate the theory that proximity to spawning streams is an important habitat selection criterion.

CONCLUSIONS AND RECOMMENDATIONS

LURS LbP and SbP spawning streams had habitat features and attributes different than unselected LU streams. Temperature profiles of selected streams were significantly different for LbP streams which were warmer and heated more quickly than all other streams surveyed during the spring months. SbP spawning streams were the coolest surveyed and were not significantly different from one another over the spawning and incubation periods combined. The average daily temperature of several non-spawning streams was not significantly different from some or all of the LURS SbP streams although they did display more variation in daily minimum and maximum temperatures. A survey of Second Brook, used as a SbP index spawning stream, differed from unselected Lake Utopia streams in certain habitat features and attributes; it is a small stream that contains many partial barriers to upstream passage, it contained a lot of riffle and run habitat and a large proportion of the substrate is less than 1.6 cm diameter. Egg deposition was also most related to these features and attributes. Big Hike Brook, an unselected steam, was most similar to other SbP streams and may contain habitat suitable for SbP spawning; future checks of this stream during spawning season are warranted to determine if it is critical habitat. LbP spawning was not evident at Mill Lake Stream in 2014 and 2015 and further exploration of the status of this population and where it spawns is recommended in order to determine how well this population is surviving in Lake Utopia and where its important habitat resides. Barriers to upstream fish passage at Mill Lake Stream should be remedied to allow access to an already contracted spawning area. The use of Mill Lake Stream by SbP smelt should be confirmed in case it is also LURS SbP spawning habitat.

ACKNOWLEDGEMENTS

This project was made possible through the involvement and support of many individuals. I would like to extend a huge thank you to my field colleague, Jason Keyes, who actively participated in the 2015 field surveys and made the project better with his ideas and tremendous humour. I would also like to thank: Daphne Themelis for her guidance and support of the work from its beginning to end; various staff at the St. Andrews Biological Station and Conservation and Protection offices who helped out with field activities: Art MacIntyre, Tara Albright, Quinn McCurdy, Robert MacDougall; Population Ecology managers: Kirsten Clark, Tara McIntyre, and Kent Smedbol for their support of this project; DFO Species at Risk Management Division for their active support, especially Kim Robichaud-LeBlanc; and reviewers Stephanie Ratelle, Rod Bradford and Kurt Samways for their comments that enhanced the paper. Access to the three SbP streams was made possible by the amazing support of the Abony family and Ryan MacDonald who are wonderful stewards of Lake Utopia Smelt in Scout Brook.

REFERENCES

Bell, G.M. and Hoar, W.S. 1950. Some effects of ultraviolet radiation on Sockeye Salmon eggs and alevins. Can. J. Res. 28(1): 35-43.

Bradbury, I.R., Bradford, R., and Bentzen. P. 2011. Genetic and phenotypic diversity and divergence in sympatric Lake Utopia Rainbow Smelt (*Osmerus mordax*). DFO Can. Sci. Advis. Sec. Res. Doc. 2011/008.

Bradford, R.G., Bentzen, P., and Bradbury, I. 2012. Lake Utopia Rainbow Smelt (*Osmerus mordax*) status, trends, habitat considerations and threats. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/124.

Bruce, J.W. 1975. Some aspects of the biology of landlocked smelt, *Osmerus eperlanus mordax* (Mitchill) 1815, in selected Avalon Peninsula lakes. Dept. Environ., Fish. Mar. Serv., NFLD Region. Rapport numéro NEW. T-75-2.

Brylinksy, M. 2009. Lake Utopia water quality assessment. Commissioned by the NB Dept. Env..92 p.

Carr, J.W., Whoriskey, F., and O'Reilly, P. 2004. Efficacy of releasing captive reared broodstock into an imperilled wild Atlantic Salmon population as a recovery strategy. J. Fish Biol., 65 (Suppl. A): 38-54.

Copeman, D.G. 1977. Population differences in Rainbow Smelt, *Osmerus mordax*: multivariate analysis of mensural and meristic data. J. Fish. Res. Board Can., 34(8): 1220-1229.

COSEWIC. 2000. COSEWIC assessment and status report on the Lake Utopia Dwarf Smelt Osmerus sp. in Canada. Comm. Status Endan. Wildl. Can., Ottawa, Ontario. vii + 13 p. (accessed 4 April 2016).

COSEWIC. 2008. COSEWIC assessment and update status report on the rainbow smelt, Lake Utopia large-bodied population and small-bodied population Osmerus

mordax in Canada. Comm. Status Endan. Wildl. Can. Ottawa, Ontario. vii + 28 p. (accessed 4 April 2016).

Creaser, C.W. 1925. The establishment of the Atlantic Smelt in the upper waters of the Great Lakes. Reprinted from Pap. Michigan Acad. Sci., Arts Lett., Vol. V: 405-424.

Curry, R.A., Currie, S.L., Bernatchez, L., and Saint-Laurent, R. 2004. The Rainbow Smelt, *Osmerus mordax*, complex of Lake Utopia: Threatened or Misunderstood? Env. Biol. Fish., 69(1-4): 153-166.

DFO. 2014. Recovery Potential Assessment for Outer Bay of Fundy Atlantic Salmon. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/021.

DFO. 2016a. Recovery Strategy for the Lake Utopia Rainbow Smelt (*Osmerus mordax*), Small-bodied Population (sympatric with the Large-bodied Population), in Canada. In Species at Risk Act Recovery Strategy Series. Ottawa: Fisheries and Oceans Canada.

DFO. 2016b. Estimating Lake Utopia Rainbow Smelt (*Osmerus mordax*) spawner abundance and allowable harm. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/024.

Eastern Charlotte Waterways (ECW). 2012. Lake Utopia Dwarf Smelt Report. 38 p. (accessed 2 April 2016).

EC. 2012. Canadian Aquatic Biomonitoring Network. Field manual: Wadeable streams. 57 p.

Hoover, E.E. 1936. The spawning activities of fresh water smelt, with special reference to the sex ratio. Copeia, 1936(2): 85-91.

IKANAWTIKET Environmental Incorporated. 2014. Presence/Absence of Lake Utopia Rainbow Smelt (Osmerus mordax) Large-bodied Population and Small-bodied Population April - May 2014 Spawning Run Field Study. 26 p. (accessed 25 May 2016).

Langlois, T.H. 1935. Notes on the spawning habits of the Atlantic Smelt. Copeia, 1935(3): 141-142.

Lanteigne, J., and McAllister, D.E. 1983. The Pygmy Smelt, *Osmerus spectrum* Cope, 1870, a forgotten sibling species of Eastern North American fish. Syllogeus 45: 1-32.

Lecomte, F., and Dodson, J.J. 2005. Distinguishing trophic and habitat partitioning among sympatric populations of the estuarine fish *Osmerus mordax* Mitchill. J. Fish Biol., 66(6): 1601-1623.

Legault, R.O., and Delisle, C. 1968. La fraye d'une population d'éperlans géants, *Osmerus eperlanus mordax*, au lac Heney, Comté de Gatineau, Québec. J. Fish. Res. Board Can., 25(9): 1813-1830.

MacLeod, N. 1922. An investigation of the Lake Utopia Smelt. Biol. Board Can., Atlantic Biological Station, St. Andrews, N.B.

McKenzie, R.A. 1947. The effects of crowding of smelt eggs on the production of larvae. Fish. Res. Board Can. Atl. Res. Stat. Prog. Rep., 39: 11-13.

McKenzie, R.A. 1964. Smelt life history and fishery in the Miramichi River, New Brunswick. Fish. Res. Board Can., Bull. 144.

NATECH Environmental Services Inc. 2009. Hydraulic performance of the Canal at Lake Utopia. 24 p.

Nellbring, S. 1989. The ecology of smelts (genus *Osmerus*): A literature review. Nord. J. Freshw. Res., 65: 116-145.

Osgood, J.R. Co. 2013. The Maritime Provinces: A Handbook for travelers, a Guide to the Chief. London: Forgotten Books. 404 p. (Original work published 1875).

Peake, S.J. 2008. Swimming performance and behaviour of fish species endemic to Newfoundland and Labrador: A literature review for the purpose of establishing design and water velocity criteria for fishways and culverts. Can. Manuscr. Rep. Fish. Aquat. Sci. 2843.

Plosila, D.S. 1984. Spacial(sic) distribution of rainbow smelt spawning in the New York waters of Lake Champlain. NY Fish Game J., 31(1): 109-111.

Rivard, J. 2016. Ecological Speciation of a Landlocked Population of Rainbow Smelt (*Osmerus mordax*) in Lochaber Lake, Nova Scotia. Thesis (M.Sc.) Dalhousie University, Halifax, N.S. 106 p.

Rothschild, B.J. 1961. Production and survival of eggs of the American Smelt, *Osmerus mordax* (Mitchill), in Maine. Trans. Amer. Fish. Soc., 90(1): 42-48.

Rupp, R.S. 1959. Variation in the life history of the American Smelt in inland waters of Maine. Trans. Am.. Fish. Soc., 88(4): 241-252.

Rupp, R.S. 1965. Shore-spawning and survival of eggs of the American Smelt. Trans. Am. Fish. Soc., 94(2): 160-168.

St. George Power Limited Partnership. 2012. Fisheries Management Plan St. George Power LP. 33 p.

Scott, W.B., and Crossman, E.J. 1973. Freshwater fishes of Canada. Can. Fish. Res. Board Can. Bull. No. 184.

Shaw, J. 2006. Variation in early life-history characteristics of sympatric Rainbow Smelt populations in Lake Utopia, New Brunswick. MSc thesis. University of New Brunswick, Fredericton, New Brunswick. vii + 61 p.

Shaw, J.L., and Curry, R.A., 2011. Ontogenetic divergence of growth among rainbow smelt morphotypes. Env. Biol. Fish., 92(2): 217-227.

Taylor, E.B., and Bentzen, P.B., 1993. Molecular genetic evidence for reproductive isolation between sympatric populations of smelt *Osmerus* in Lake Utopia, south-western New Brunswick, Canada. Molec. Ecol., 2(6): 345-357.

Zagarese, H.E., and Williamson, C.E., 2001. The implications of solar UV radiation exposure for fish and fisheries. Fish Fish., 2(3): 250-260.

TABLES

Table 1. Mean temperatures (°C) for Lake Utopia Streams for date periods specified in 2014. Asterisk indicates significant differences among streams for that time interval ($p<0.05$).

Stream	LbP Period March 23- April 30 (°C)	SbP Period April 23- May 30 (°C)	SbP Pre-spawn/Spawn Period April 23- May 7 (°C)	SbP Incubation Period May 8- May 30 (°C)
Mill Lake Stream	3.59 ± 2.0*	12.01 ± 3.56*	8.07 ± 1.78	14.57 ± 1.38
Second Brook	1.94 ± 1.81	7.84 ± 2.14	5.56 ± 1.07	9.33 ± 1.06
Unnamed Brook	1.61 ±1.27	6.15 ± 1.88	4.13 ± 0.86	7.48 ± 0.92
Smelt Brook	1.60 ± 1.42	6.89 ± 2.16	4.52 ± 0.96	8.44 ± 1.00
Otter Brook	2.21 ± 1.88	9.37 ± 2.84	6.31 ± 1.65	11.37 ± 1.15
Big Hike Brook	1.76 ± 1.18	6.36 ± 2.02	4.14 ± 0.83	7.81 ± 0.95
Leavitt's Cove Brook	2.15 ± 1.79	8.49 ± 2.58	5.73 ± 1.37	10.29 ± 1.20

Table 2. Kruskal-Wallis multiple comparison test results for the LbP Spawning/Incubation period of March 23 to April 30, 2014. True (green squares) indicates a significant difference between streams with p-value less than 0.05 and observed differences less than the critical difference of 54.31841. False indicates no significant difference between streams. Squares with X indicate that the stream comparison result is presented in another square in the table.1. LbP stream; 2. SbP stream.

	Leavitt's Cove Brook	Big Hike Brook	Otter Brook	Mill Lake Stream[1]	Second Brook[2]	Smelt Brook[2]	Unnamed Brook[2]
Unnamed Brook*	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	X
Smelt Brook*	FALSE	FALSE	FALSE	TRUE	FALSE	X	X
Second Brook*	FALSE	FALSE	FALSE	TRUE	X	X	X
Mill Lake Stream**	TRUE	TRUE	TRUE	X	X	X	X
Otter Brook	FALSE	FALSE	X	X	X	X	X
Big Hike Brook	FALSE	X	X	X	X	X	X
Leavitt's Cove Brook	X	X	X	X	X	X	X

Table 3. Kruskal-Wallis multiple comparison test results for the SbP Spawning/Incubation period of April 23 to May 30, 2014. True indicates a significant difference between streams with p-value less than 0.05 and observed differences less than the critical difference of 53.62007. False indicates no significant difference between streams. Squares with X indicate that the stream comparison result is presented in another square in the table. 1. LbP stream; 2. SbP stream.

	Leavitt's Cove Brook	Big Hike Brook	Otter Brook	Mill Lake Stream[1]	Second Brook[2]	Smelt Brook[2]	Unnamed Brook[2]
Unnamed Brook*	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	X
Smelt Brook*	FALSE	FALSE	TRUE	TRUE	FALSE	X	X
Second Brook*	FALSE	FALSE	FALSE	TRUE	X	X	X
Mill Lake Stream**	TRUE	TRUE	FALSE	X	X	X	X
Otter Brook	FALSE	TRUE	X	X	X	X	X
Big Hike Brook	TRUE	X	X	X	X	X	X
Leavitt's Cove Brook	X	X	X	X	X	X	X

Table 4. Kruskal-Wallis multiple comparison test results for the SbP pre-spawn/spawning period of April 23 to May 7, 2014. True indicates a significant difference between streams with p-value less than 0.05 and observed differences less than the critical difference of 33.78506. False indicates no significant difference between streams. Squares with X indicate that the stream comparison result is presented in another square in the table. 1 LbP stream;2. SbP stream.

	Leavitt's Cove Brook	Big Hike Brook	Otter Brook	Mill Lake Stream[1]	Second Brook[2]	Smelt Brook[2]	Unnamed Brook[2]
Unnamed Brook*	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	X
Smelt Brook*	FALSE	FALSE	FALSE	TRUE	FALSE	X	X
Second Brook*	FALSE	FALSE	FALSE	FALSE	X	X	X
Mill Lake Stream**	FALSE	TRUE	FALSE	X	X	X	X
Otter Brook	FALSE	TRUE	X	X	X	X	X
Big Hike Brook	FALSE	X	X	X	X	X	X
Leavitt's Cove Brook	X	X	X	X	X	X	X

Table 5. Kruskal-Wallis multiple comparison test results for the SbP Late Spawning/ Incubation period of May 8 to May 30, 2014. True indicates a significant difference between streams with p-value less than 0.05 and observed differences less than the critical difference of 41.76662. False indicates no significant difference between streams. Squares with X indicate that the stream comparison result is presented in another square in the table. 1. LbP stream; 2. SbP stream.

	Leavitt's Cove Brook	Big Hike Brook	Otter Brook	Mill Lake Stream[1]	Second Brook[2]	Smelt Brook[2]	Unnamed Brook[2]
Unnamed Brook*	TRUE	FALSE	TRUE	TRUE	TRUE	FALSE	X
Smelt Brook*	TRUE	FALSE	TRUE	TRUE	FALSE	X	X
Second Brook*	FALSE	FALSE	FALSE	TRUE	X	X	X
Mill Lake Stream**	TRUE	TRUE	FALSE	X	X	X	X
Otter Brook	FALSE	TRUE	X	X	X	X	X
Big Hike Brook	TRUE	X	X	X	X	X	X
Leavitt's Cove Brook	X	X	X	X	X	X	X

Table 6. Daily average lake height and velocity of water at the primary culvert at Mill Lake Stream 2015. Also noted is the relative height of the water flowing through the primary culvert.

Date	Daily Average Lake Height (ft.)	Water velocity at centre of primary culvert (m/s)	Observed fill level of water in culvert
April 13	17.2	1.08	25%
April 15	17.74	1.18	50%
April 17	18.23	0.62	>75%
April 20	18.46	0.50	100%
April 30	18.50	0.41	100%

Table 7. Geographic Upper limit of eggs in three SbP LURS spawning streams in 2015 compared with Critical Habitat limits presented in the Recovery Strategy (DFO 2016a).

Brook	Upper Limit (DFO 2016a)	Upper Limit 2015	Shift
Second	45.2102778°N 66.789444°W	45.210359°N 66.788807°W	upstream
Unnamed	45.21°N, 66.8091667°W	45.20992°N 66.80833°W	downstream
Smelt	45.206666°N 66.8152778°W	45.206570°N 66.814840°W	downstream

Table 8. Proportion (%) of substrate composition in 3 LURS SbP streams in 2002.

Substrate Category	Second Brook (% composition)	Unnamed Brook (% composition)	Smelt Brook (% composition)
Bedrock	0	0	0
Boulder (>461 mm)	0.74	2.7	2
Rock (180-460 mm)	1.11	4.5	4.2
Rubble (54-179 mm)	0	1.8	3.3
Gravel (2.6-53 mm)	16.5	10	15.3
Sand (0.06-2.5 mm)	63.3	63.5	47.5
Fines (0.0005-0.05 mm)	18.3	17.3	27.8

Table 9. Earliest observation dates and temperatures for adult smelt presence in Mill Lake Stream. Dates recorded are the dates of first smelt observations in a given observation year.

Year	Earliest Date Observed	Temperature (°C)	Reference/Source
1922	April 11	NA	MacLeod (1922)
1980	April 7	4	Lanteigne and McAllister (1983)
1999	April 2	<6	Curry et al. (2004)
2002	April 11	NA	Bradford et al. 2012
2003	April 13	NA	Bradford et al. 2012
2004	April 16	5	Shaw (2011)
2009	April 16	NA	Bradford et al. 2012
2012	April 6	5.5	ECW (2012)
2013	April 3	NA	IKANAWTIKET (2013)
2014	April 1	<1	DFO (unpubl.)
2015	None observed	<2 (April 2)	This Study

Table 10. Earliest observation dates and temperatures for adult smelt presence for SbP LURS. Dates recorded are the dates of first smelt observations in a given observation year.

Year	Earliest Date Observed	Second Brook (°C)	Unnamed Brook(°C)	Smelt Brook (°C)	Mill Lake Stream (°C)	Reference/Source
1981	May 12	-	-	Not provided	-	Lanteigne and McAllister (1983)
1999	April 21	<6	<6	-	-	Curry et al. 2004
1999	April 26	-	-	<9	-	Curry et al. 2004
1999	May 3	-	-	-	-	Curry et al. 2004
2002	April 17		4.5**			NBDNR
2002	April 22	4**		3.5**		NBDNR
2004	April 27	NA	NA	NA	-	Shaw (2006)
2012	April 13	-	4.5	6.8	-	ECW (2012)
2012	April 16	7.1	5.3	-	-	ECW (2012)
2012	April 20	9.8	6.9	7.5	-	ECW (2012)
2012	April 30	-	6.6*	-	-	ECW (2012)
2012	May 4	-		9.3	-	ECW (2012)
2013	May 1	8.1**	6.1**	6.6**	-	DFO (unpubl.)
2014	April 22	-	-	-	5.8	IKANAWTIKET (2014)/ DFO
2014	May 2	None seen	5.1	5.7	-	IKANAWTIKET (2014)
2015	April 29	-	-	-	6.2*	This Study
2015	May 4/5	7.2**	6.6**	7.3**	-	This Study

*Eggs observed, **Eggs and Smelt observed

FIGURES

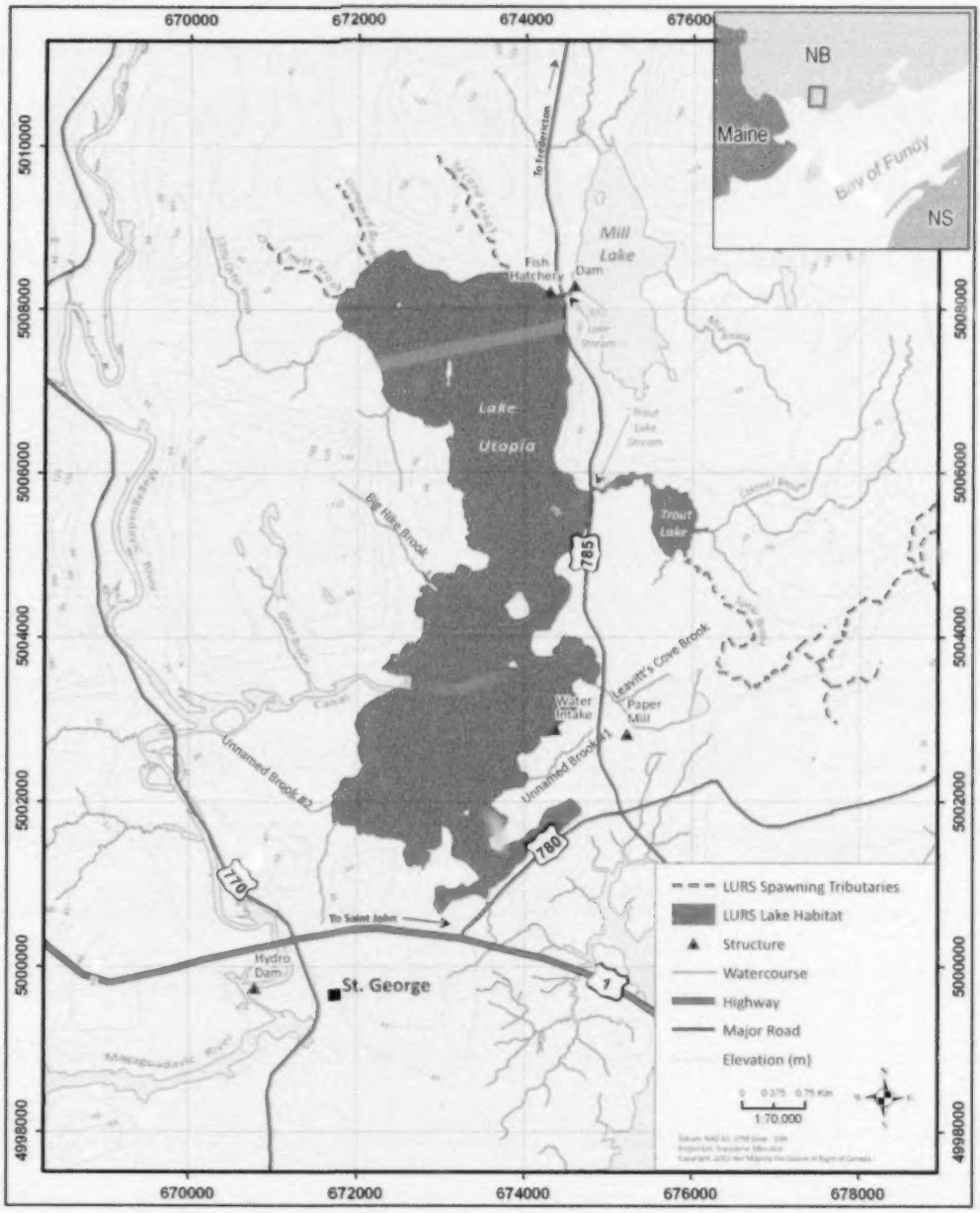


Figure 1. Lake Utopia, New Brunswick and its associated tributaries.

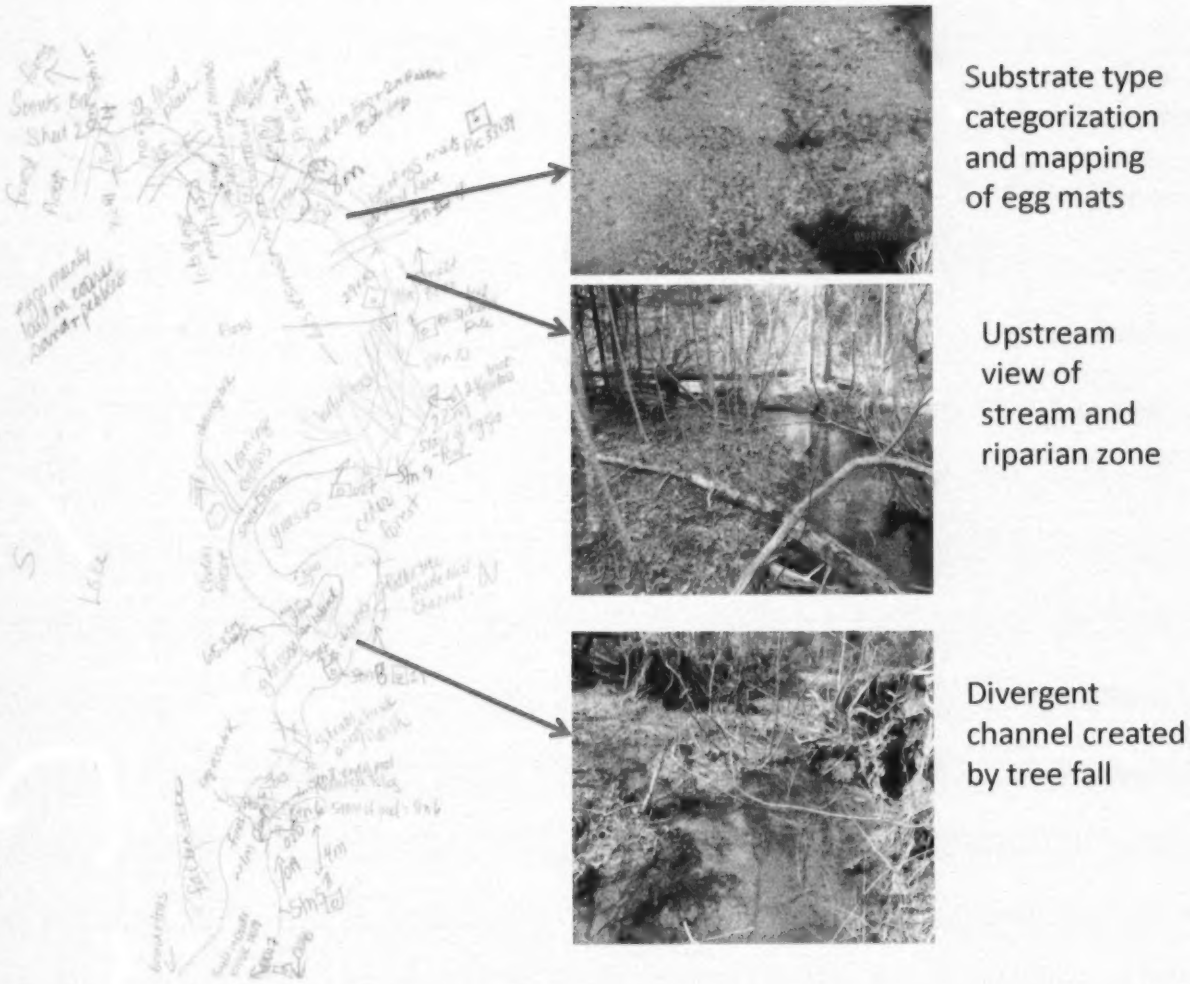

Substrate type categorization and mapping of egg mats
Upstream view of stream and riparian zone
Divergent channel created by tree fall

Figure 2. Sample of habitat mapping of the lower portion of Second Brook.

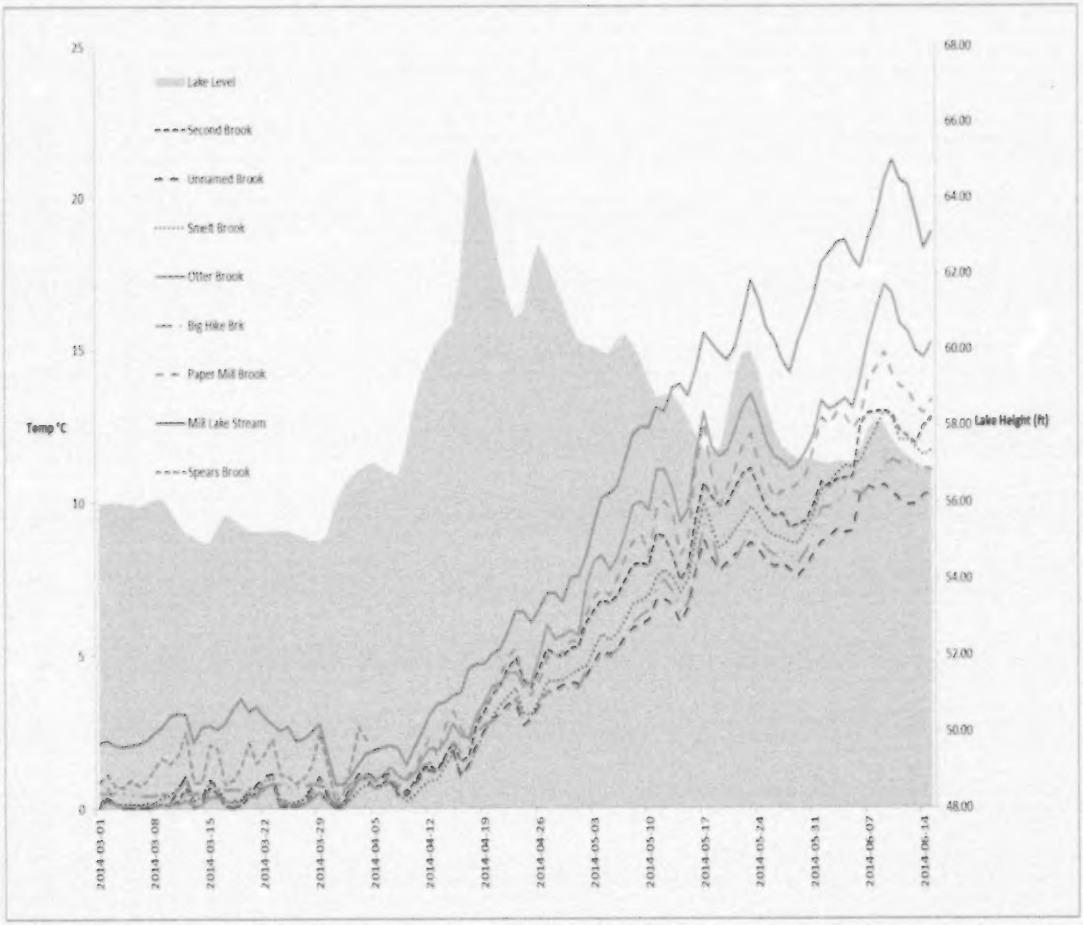


Figure 3. Daily average stream water temperatures and daily average LakeUtopia water levels from March 1, 2014 to June 15, 2014. Known spawning streams are represented by red coloured lines, non-spawning streams by green lines and known large-bodied LURS spawning streams in blue.

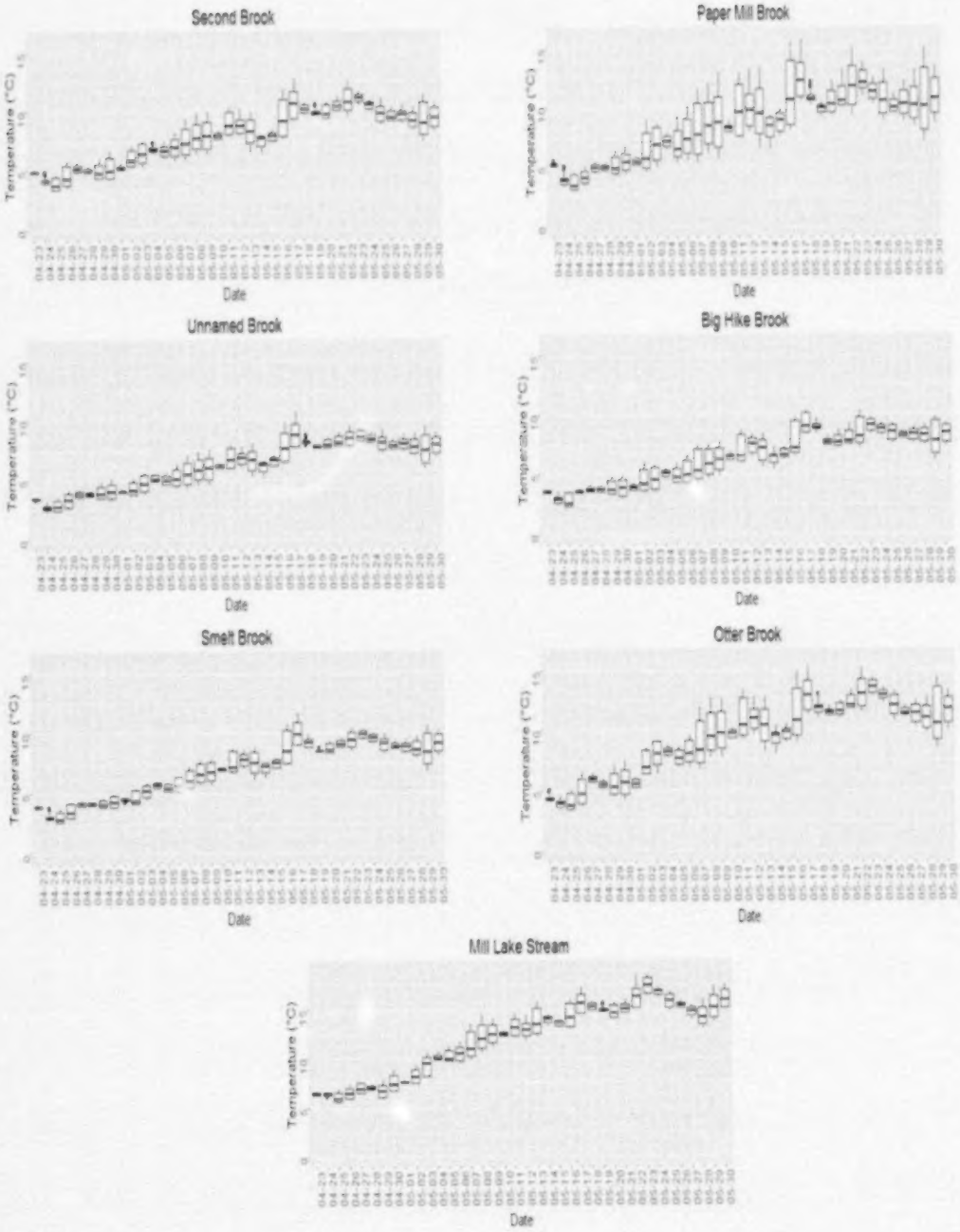


Figure 4. Boxplots of daily temperatures (one per hour) for known LURS SbP spawning streams (left column), non-spawning stream (right column) and a LURS LbP spawning stream (centre bottom) for the SbP LURS spawning and incubation period from April 23 to May 30, 2014. The line in each box represents the median temperature for each date and the whiskers indicate minimum and maximum temperatures.

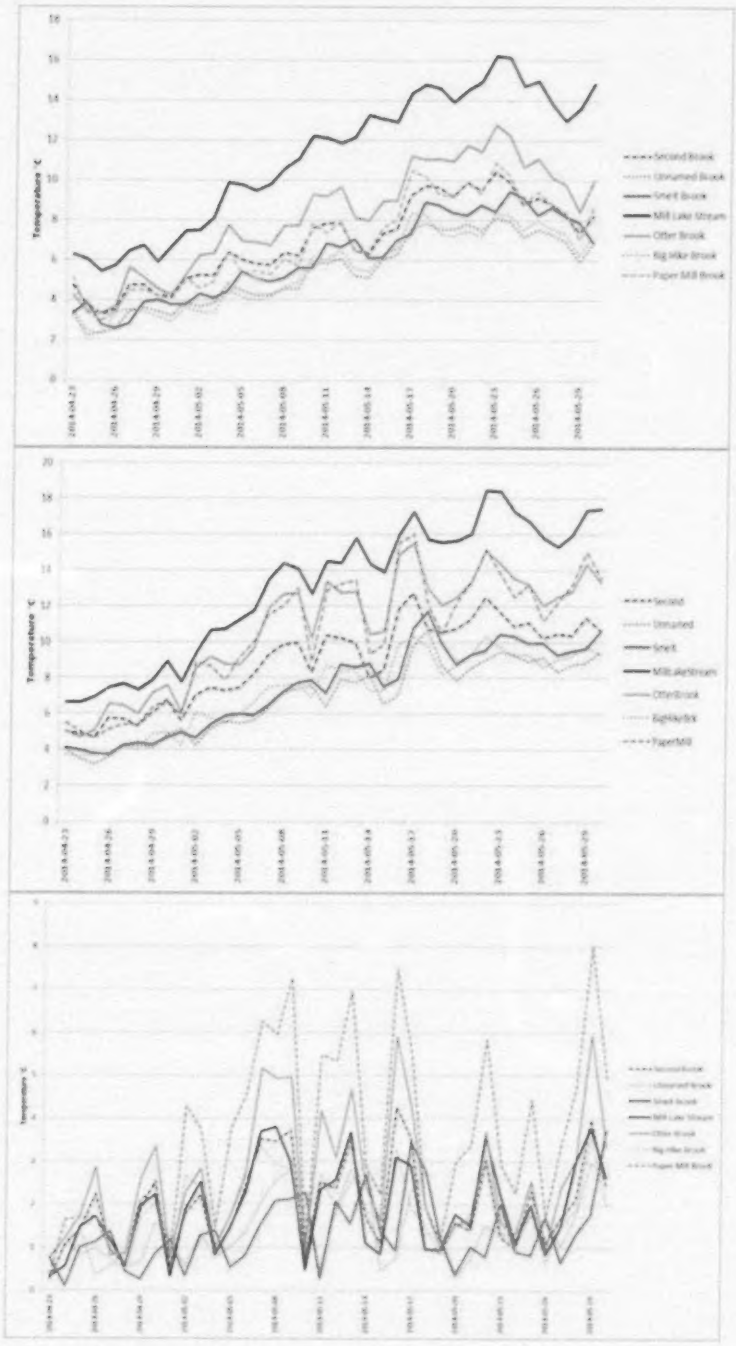


Figure 5. Daily minimum temperatures (top), daily maximum temperatures (middle) and temperature ranges (bottom) for the 2014 LURS small bodied spawning and incubation period (April 23-May 30). Known SbP spawning streams are represented by red lines, non-spawning streams are in green, and LbP spawning stream in black.

a

b

Figure 6. Upstream barrier on Second Brook in 2015. a) barrier of wood debris and leaves that create a strong water flow through a small opening b) barrier partially removed to create a wider opening and decrease water flow.

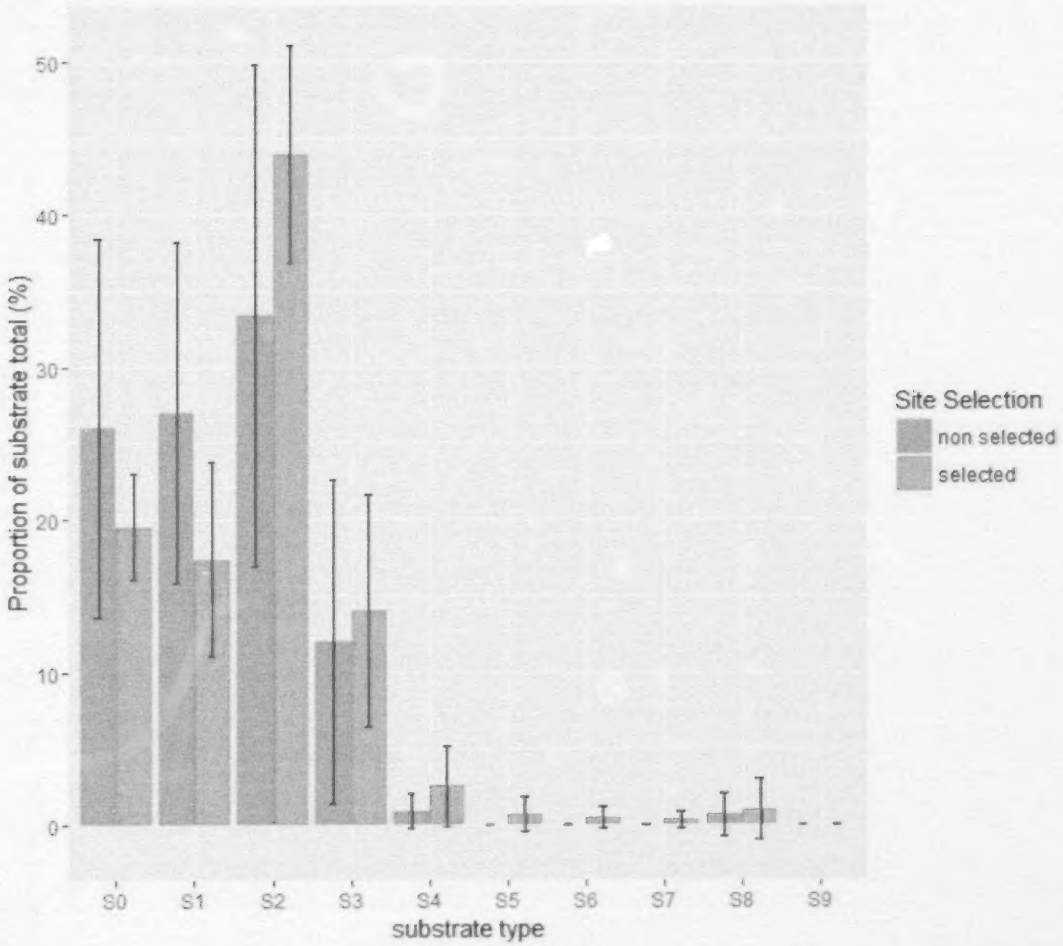


Figure 7. Substrate type proportions in selected (eggs present) and non-selected (no eggs present) smelt habitat. Substrate type categories are differentiated by particle size : S0=organic cover, S1= fine sand, silt or clay (<0.1 cm), S2= coarse sand (0.1-0.2 cm), S3= gravel (0.2-1.6 cm), S4= small pebble (1.6-3.2 cm), S5= large pebble (3.2-6.4 cm), S6= small cobble (6.4-12.8 cm), S7= cobble (12.8-25.6 cm), S8= boulder (>25.6 cm), S9= bedrock. Coloured bars with error bars indicate the mean proportion of each substrate size category for selected and non-selected sites with their standard error of the mean.

a

b

c

Figure 8. Otter Brook Habitat Photographs a) downstream towards opening in Canal b) stream in forested section c) typical substrate composition.

a

b

Figure 9. Leavitt's Cove Brook habitat photographs a) downstream towards opening with Lake Utopia b) upstream into forested area.

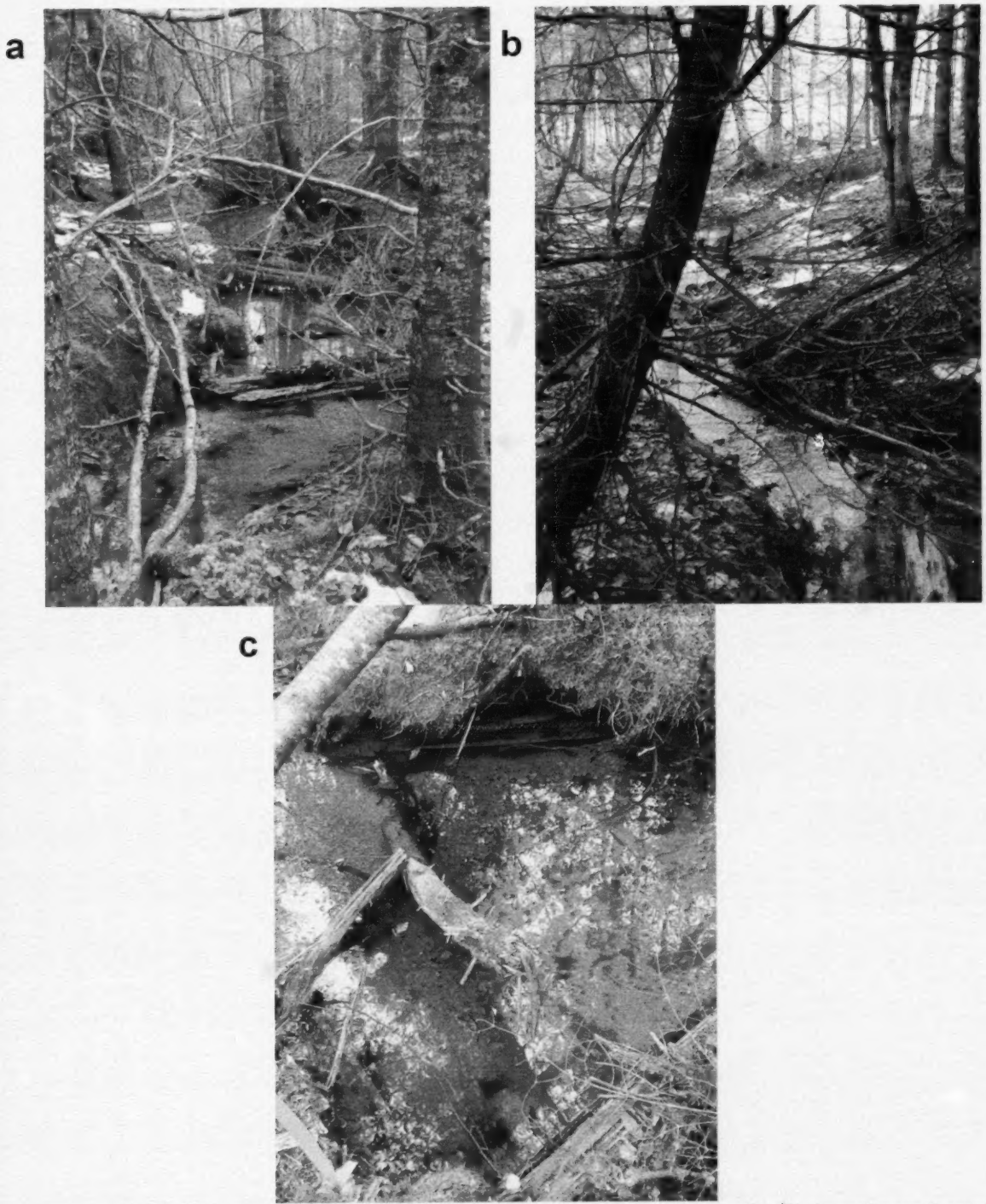


Figure 10. Big Hike Brook habitat photographs a)Upstream into forested section b) downstream through forested section towards drainage area into Lake Utopia c) sand and clay substrate.

a

b

Figure 11. Unnamed Brook #1 habitat photographs a) swampy area at downstream opening b) stream channel and woody debris (foreground) blocking stream.

Figure 12. Unnamed Brook #2 with a beaver lodge and dam near opening of stream to lake.

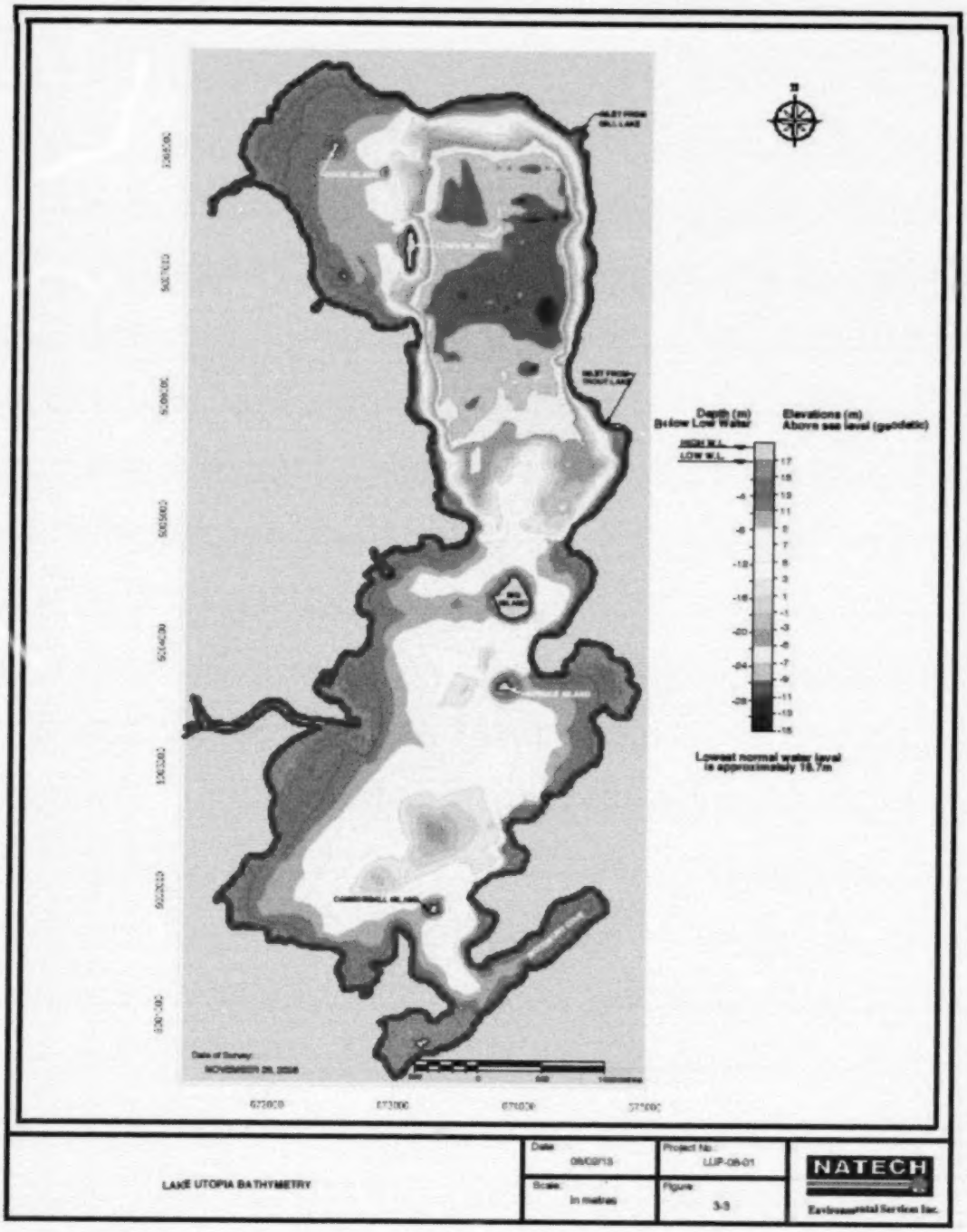


Figure 13. Bathymetric map of Lake Utopia. Reprinted with permission from NATECH Environmental Services Inc.

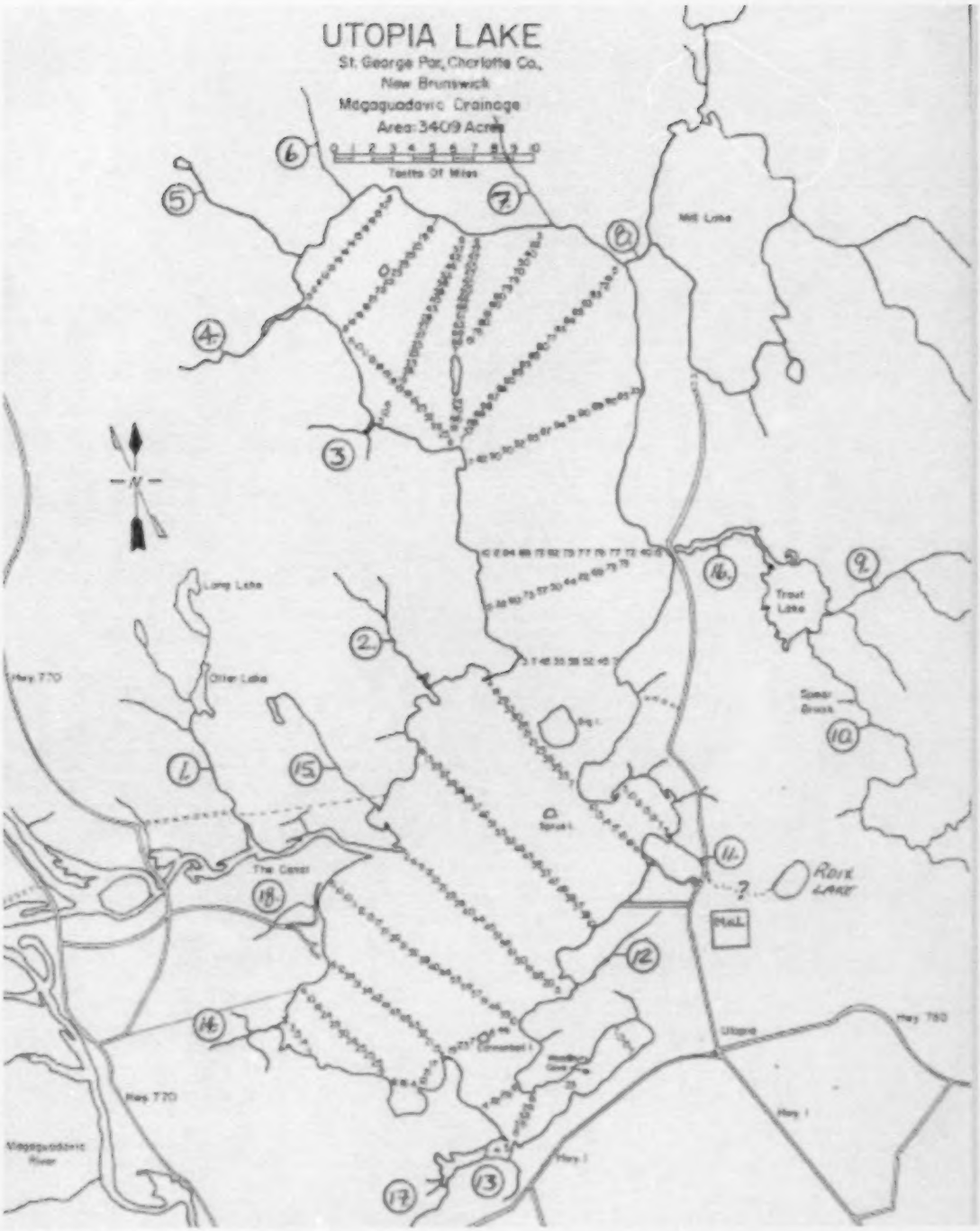
APPENDIX

Appendix Table 1. Results of 2002 Lake Utopia Tributary Survey conducted by the New Brunswick Department of Natural Resources for the Department of Fisheries and Oceans.

DATE	KNOWN TRIBUTARY TYPE	TRIBUTARY NAME	LEGEND NO.	TEMP. (°C)	OBSERVATIONS
16-Apr-02	LbP Spawning	Mill Lake Stream	8	7.00	eggs present (medium/heavy) downstream from falls, no fish present
16-Apr-02	LbP Spawning	Spear Brook	10	4.50	eggs present (light) for 10 m downstream from beaver dam, no fish present
16-Apr-02		Colonial Brook	9	7.00	no eggs present, no fish present, highly braided, little fish access, no potential for spawning smelt
17-Apr-02		Lake Utopia		6.00	
17-Apr-02	SbP Spawning	Unnamed Brook	6	4.50	eggs present (medium), fish present (2)
17-Apr-02	SbP Spawning	Mill (Smelt) Brook	5	5.00	no eggs present, no fish present, potential for spawning
17-Apr-02	SbP Spawning	Scout (Second) Brook	7	6.00	no eggs present, no fish present, potential for spawning
22-Apr-02	SbP Spawning	Mill (Smelt) Brook	5	3.50	fish present (1000's 10-15 cm), eggs present, 2 pm
22-Apr-02	SbP Spawning	Unnamed Brook	6	4.00	eggs present (medium/heavy), no fish present
22-Apr-02		Lake Utopia		7.00	
22-Apr-02	LbP Spawning	Spear Brook	10	5.50	eggs present (light), no fish present
22-Apr-02	LbP Spawning	Mill Lake Stream	8	7.50	eggs present (eyed), no fish present
22-Apr-02	SbP Spawning	Scout (Second) Brook	7	4.00	eggs present (medium/scattered), fish present (100's)
23-Apr-02		Otter (Sucker) Brook	1	6.00	no eggs present, no fish present, potential for spawning, no access restriction, blockage 1 m off upstream side of Quarry Rd
23-Apr-02		"Spinneys Camp" Brook	2	6.50	no potential for spawning, brook dries up 150 m from lake
23-Apr-02		"NE Greys Mtn" Brook	3	5.00	no eggs present, no fish present, beaver dam ~ 150 m from lake, poor flow, poor substrate, low potential for spawning
24-Apr-02		?		NA	no eggs present, no fish present, no potential for spawning
24-Apr-02		Roix Lake Brook	11	5.00	no eggs present, no fish present, medium potential for spawning up to falls (50 m upstream), good flow, poor substrate
24-Apr-02		North of the P&P Mill Brook	12	4.00	no eggs present, no fish present, no potential for spawning
24-Apr-02		?	b	NA	no potential
24-Apr-02		?	c	NA	no potential
24-Apr-02		Woodburry Cove Brook "A"	13	NA	no potential
24-Apr-02		Troaks Mtn Brook	14	4.50	no potential for spawning

DATE	KNOWN TRIBUTARY TYPE	TRIBUTARY NAME	LEGEND NO.	TEMP. (°C)	OBSERVATIONS
24-Apr-02		Canal Beach Brook	18	9.00	no potential for spawning
24-Apr-02		Lake Utopia (@ canal beach)		8.00	
24-Apr-02	SbP Spawning	Unnamed Brook	6	4.50	more eggs present since 22-Apr-02, no fish present in brook, fish caught in minnow trap (88)
24-Apr-02	SbP Spawning	Scout Brook	7	5.00	eggs (light), smelt present (100's), 5pm
29-Apr-02		Otter(Sucker) Brook	1	4.00	no fish present, sucker eggs and small "smelt sized" eggs collected 10:30am
29-Apr-02	LbP Spawning	Mill Lake Stream	8	6.30	eggs present(eyed), no new eggs present, no fish present, 12pm
29-Apr-02	SbP Spawning	Scout Brook	7	3.00	no new eggs present(eggs are not eyed yet) some density, approx 300 fish present, 1pm
30-Apr-02	SbP Spawning	Unnamed Brook	6	3.00	many eggs present(medium), no eyed eggs, approx. 50 fish in stream, 12:30pm
30-Apr-02	SbP Spawning	Mill (Smelt) Brook	5	3.50	many eggs present(medium-thick/substrate covered), fish present(10,000+,maybe up to 50,000)
30-Apr-02	SbP Spawning	Scout Brook	7	3.00	no new eggs present(eggs are not eyed yet) some density, approx 100 fish present
01-May-02	SbP Spawning	Mill (Smelt) Brook	5	3.00	many eggs present(medium-thick/substrate covered), fish present(same as Apr 30th), Mark-recapture method used
01-May-02	SbP Spawning	Unnamed Brook	6	4.00	most areas of stream have a 1.5 cm egg mat, some areas have 2.5cm egg mats, no fish present
01-May-02	SbP Spawning	Scout Brook	7	4.00	no new eggs present(eggs are not eyed yet) some density, more smelt than yesterday, approx. 2000 smelt present
01-May-02	LbP Spawning	Mill Lake Stream	8	7.00	no new eggs, no fish present
07-May-02	LbP Spawning	Spear Brook	10	9.00	no new smelt eggs, sucker eggs, smelt eggs eyed and larvae swimming in eggs (eggs in same area), six 3-4 cm trout fry
07-May-02		Colonel Brook	9	12.00	no smelt eggs from lake upstream to falls, sucker eggs in west channel, no eggs in east channel,
07-May-02	SbP Spawning	Scout Brook	7	NA	no fish, 4:00 pm
06-May-02	SbP Spawning	Mill (Smelt) Brook	5	7.00	1:00 pm, no fish present, eggs not eyed
06-May-02	SbP Spawning	Unnamed Brook	6	7.00	1:30 pm, no fish present in brook, 169 fish caught in minnow trap, more eggs, eggs not eyed
06-May-02		Scout Brook	7	9.00	2:30 pm, more eggs, thickest egg mat 1m x 2m x 1 cm, decrease in number of smelt
06-May-02	LbP Spawning	Mill Lake Stream	8	11.50	3:30 pm, no new eggs, eggs eyed and larvae swimming in eggs, no fish
08-May-02		Otter (Sucker) Brook	1	9.00	11:30 am, no eggs, no fish, fine sedimentation/silt, low potential for spawning
08-May-02	SbP Spawning	Mill (Smelt) Brook	5	8.00	2:00 pm, eggs not eyed, less than 200 smelt, majority of smelt are male (caught 2 female, 8 male)

DATE	KNOWN TRIBUTARY TYPE	TRIBUTARY NAME	LEGEND NO.	TEMP. (°C)	OBSERVATIONS
08-May-02	SbP Spawning	Unnamed Brook	6	8.00	2:50 pm, no fish, eggs not eyed, thick egg mat
09-May-02		Lake Utopia (@ brook 11)		10.00	12:10 PM
09-May-02		"Roix Lake" Brook	11	NA	dried up, no potential
09-May-02			b	NA	no fish, no eggs, dark substrate, covered with silt (polluted by mill?), no potential
09-May-02		North of the P&P Mill Brook	12	7.00	silt, leaf litter, low flow, no potential for spawning
09-May-02		Lake Utopia (@ brook 12)		9.00	
09-May-02		Woodburry Cove Brook "A"	13	NA	no potential for spawning
09-May-02		Troaks Mtn Brook	14	NA	no potential for spawning
09-May-02		Lake Utopia (@ brook 14)		10.50	
09-May-02		Canal Beach Brook	18	NA	no potential for spawning
09-May-02		Lake Utopia (@ brook 18)		11.00	
09-May-02		"NE Greys Mtn" Brook	3	9.00	no potential for spawning
09-May-02	SbP Spawning	Unnamed Brook	6	7.00	no fish in brook, 64 fish caught in minnow trap, eggs not eyed
10-May-02	SbP Spawning	Unnamed Brook	6	7.00	8:28 pm, no fish in brook, eyed eggs at bottom of mat, newer eggs on top of mat, mat 5 cm thick in some areas, water level low
10-May-02	SbP Spawning	Mill (Smelt) Brook	5	7.50	8:50 pm, few fish (6-8), no eyed eggs found
10-May-02	SbP Spawning	Scout Brook	7	8.50	9:10 pm, no fish present, no eyed eggs found
12-May-02	SbP Spawning	Unnamed Brook	6	6.00	11:30 pm, no fish in brook, one smelt in minnow trap, egg mat 7 cm thick in some areas
12-May-02	SbP Spawning	Scout Brook	7	8.50	2:30 pm, no fish in brook
12-May-02	SbP Spawning	Mill (Smelt) Brook	5	8.00	no fish present, no eyed eggs found, smelt in minnow trap
12-May-02		Lake Utopia		10.00	
13-May-02	SbP Spawning	Scout Brook	7	7.50	12:00 pm, no smelt present, one brook trout (8 cm), no eyed eggs found
13-May-02	SbP Spawning	Unnamed Brook	6	7.00	1:00 pm, no fish present in brook, no new eggs found (on burlap)
13-May-02		Lake Utopia		12.00	12:40 PM
13-May-02	SbP Spawning	Mill (Smelt) Brook	5	7.00	1:20 pm, smelt in minnow trap, one brook trout (6 cm), no new eggs found (on burlap)
13-May-02		Woodburry Cove Brook "A"	13	NA	Brook is dry, no water from culvert, no potential for spawning
13-May-02		Woodburry Cove Brook "B"	17	8.50	mud/silt bottom, 0.1 to 1.0 m wide, aprox. 1 cm to 7 cm deep, little access for fish, no potential for spawning



Appendix Figure 1. Map of Lake Utopia Tributaries surveyed in 2002. Survey streams are labelled with circled numbers. Associated stream names can be found in Appendix Table 1.